IEEJ Outlook 2019

Energy transition and a thorny path for 3E challenges

Energy, Environment and Economy

The Institute of
Energy Economics, Japan

While a decade has passed since the global financial crisis (referred to as the crisis that could come only once in a century), the world is still influenced by fallout from it. U.S. stock prices hit record high levels in 2018. With financial assistance, Greece has broken away from the European Union. Industrial production of the member countries of the Organisation for Economic Cooperation and Development has recovered to its pre-crisis level. However, an exit from anti-crisis monetary easing in the United States and Europe has caused speculation about capital flight and credit insecurity for some emerging economies, leading to their currencies' depreciation. China is in over-indebtedness after implementing an economic stimulus package worth as much as $600 billion to counter the financial crisis. At the same time, the United States' "me first" policy has become a new risk, inflaming concerns about a trade or currency war.

A decline in momentum for international cooperation has affected not only the overall economy but also energy security. A decade ago, a big challenge for energy security was record-high crude oil prices above $145 per barrel. Now attracting attention are U.S.-Iran tensions and the deterioration of Saudi Arabia's relations with neighbouring countries, which have helped to push oil prices up to around $70/bbl, after two plunges since the financial crisis. There are serious concerns that these factors, combined with already decreasing production in Venezuela and Libya, could trigger energy supply disruptions and become a great global threat.

Supply disruptions are not unique to oil. As society grows more advanced, the stable supply of electricity becomes indispensable as a social infrastructure. In addition to traditional disasters and equipment predicaments, changes in power generation methods and cyberattacks are feared to trigger electricity supply disruptions. More and more it will be important to introduce measures for securing a stable supply of the energy source that is not easy to store but that should not be deficient, even for a moment.

The factors affecting energy security are not limited to evil intentions nor unexpected contingencies. In a bid to address climate change, some sectors have growingly refrained from investing in coal-fired power plants. Unless realities mainly in Asia are considered, however, such trend may result in unacceptable consequences while it may also fail to contribute to preventing climate change.

The IEEJ Outlook 2019 not only depicts quantitative energy supply and demand through 2050 but also analyses these challenges regarding energy security in a fair and neutral manner. We believe that our attempt would widely contribute to society through the accumulation of knowledge.

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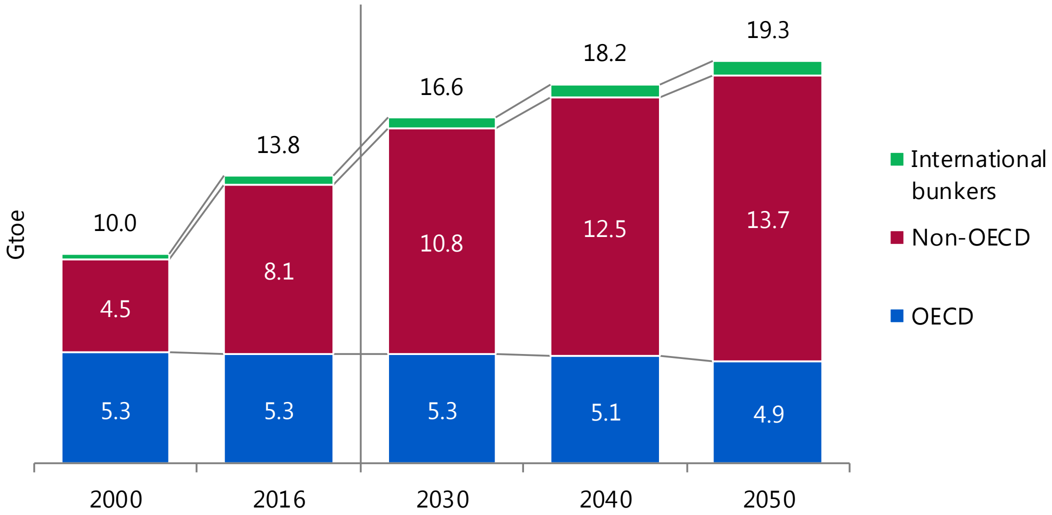
Demand

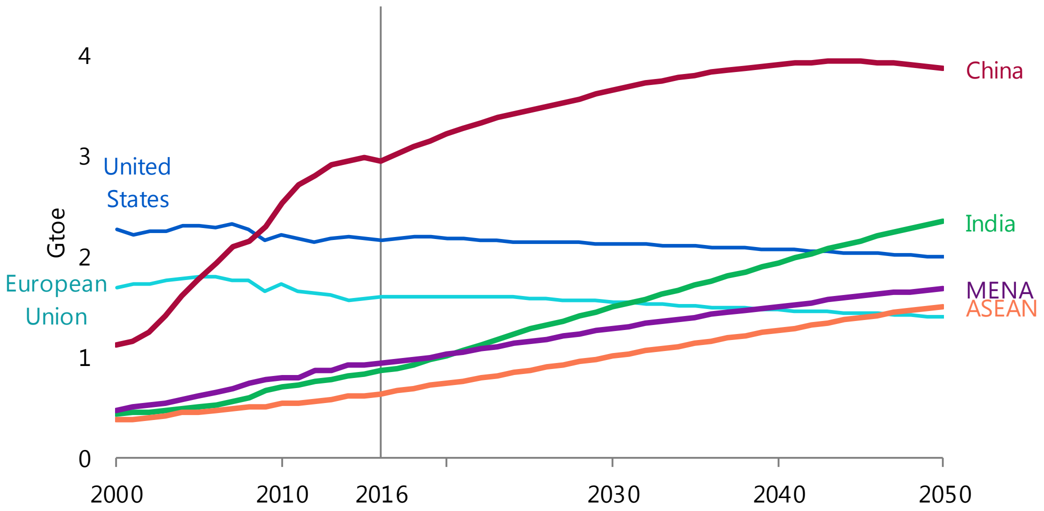
According to the Reference Scenario which reflects the transition of energy and environmental policies to this day and continues to be in a trend, the world's primary energy consumption will increase to 19.3 billion tonnes of oil equivalent (Gtoe) in 2050, due to expanding economy and increasing population (Figure 1). The growth rate of energy consumption is lower than that of real GDP due to progress in macro- and micro-energy efficiency improvement. Even so, the 5.5 Gtoe increase in energy consumption from the present level is enormous, comparable to the sum of the present consumption of China, the United States and Japan.

Figure 1 | World primary energy consumption [Reference Scenario]



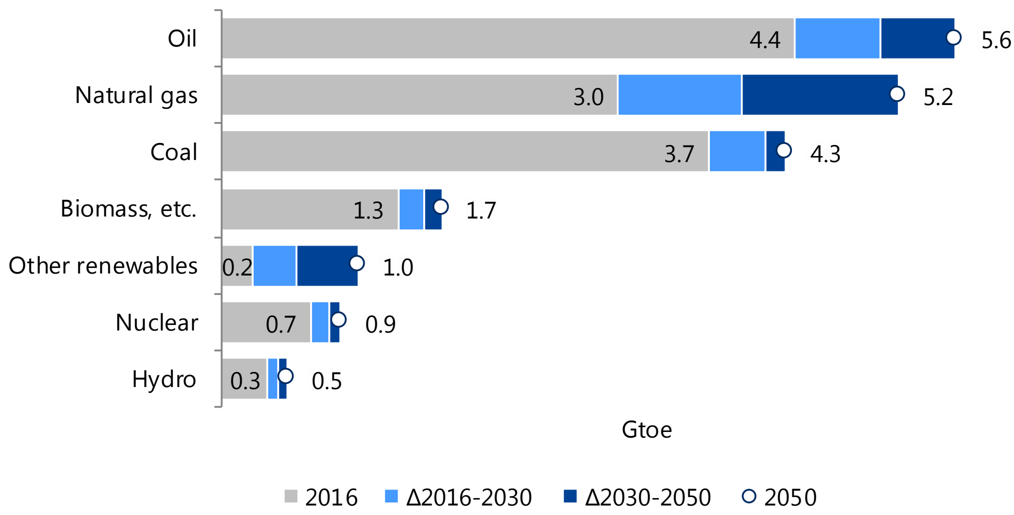
The future path of energy consumption, however, varies considerably among countries and regions. Energy consumption in Organisation for Economic Co-operation and Development (OECD) member countries will be on a steady to declining trend despite economic growth. Consequently, the net increase in energy consumption can be entirely attributable to non-OECD and international bunkers. China remains the world's largest consumer, with consumption peaking at close to 4.0 Gtoe in the mid-2040s and slightly decreasing thereafter. China is followed by the rapidly growing India and the Association of Southeast Asian Nations (ASEAN). The combined consumption of India and ASEAN in 2050 will be similar to that of China, with an increase by 2050 of 2.6 times that of China. In the Middle East and North Africa (MENA), consumption also increases significantly due to economic growth and rapid population growth (Figure 2).

Figure 2 | Primary energy consumption in selected countries and regions [Reference Scenario]



Despite high expectations for non-fossil energy, fossil fuels will remain the main source of supply for the enormous demand in the future (Figure 3). Over more than 30 years, the dependence on fossil fuels which is currently 81%, will only slightly be reduced to 79% while the consumption of fossil fuels does not decrease. The total consumption of non-fossil energy still falls short of the coal consumption, the least consumed fossil fuel in 2050. The combined increments of renewable energy are similar to the oil increments alone.

Figure 3 | World primary energy consumption [Reference Scenario]



Oil will continue to be the largest energy source supporting one third of the global energy demand in 2050. Oil consumption[1] will exceed 100 million barrels per day (Mb/d) in the mid-2020s and reach 116 Mb/d in 2050, up from the current 91 Mb/d (Figure 4). These increases are driven by non-OECD and international bunkers. Within about 10 years, China will surpass the United States as the world's largest consumer – though consumption will peak after 2040 and then decline. By the late 2040s, India will replace the United States as the second largest consumer. Although MENA is known as the region where oil-producing countries abound, it is also growing as a consuming region. In contrast, OECD consumption already peaked in 2005 and will continue to decline.

Natural gas, which is increasing faster than any other form of energy, will become the second largest energy source after oil, surpassing coal in the mid-2030s. Natural gas will be the largest energy source for the United States around 2030, for the European Union (EU) around 2040, and in the early 2020s for non-Asia. Unlike oil, there will be some natural gas consumption increases in the OECD. The non-OECD growth, however, is much larger; 8.6 times that of the OECD (Figure 5).

Figure 4 | Primary consumption of oil [Reference Scenario]

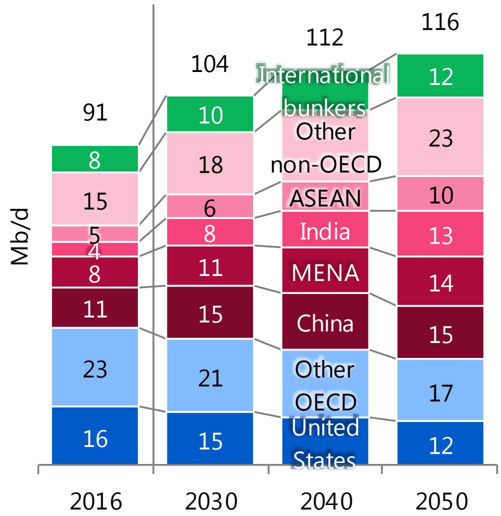
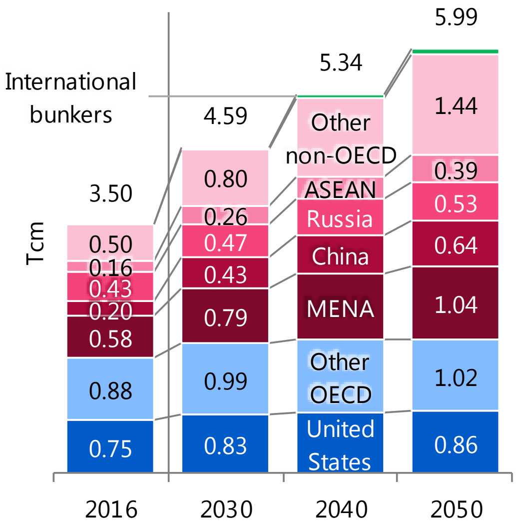


Figure 5 | Primary consumption of natural gas [Reference Scenario]



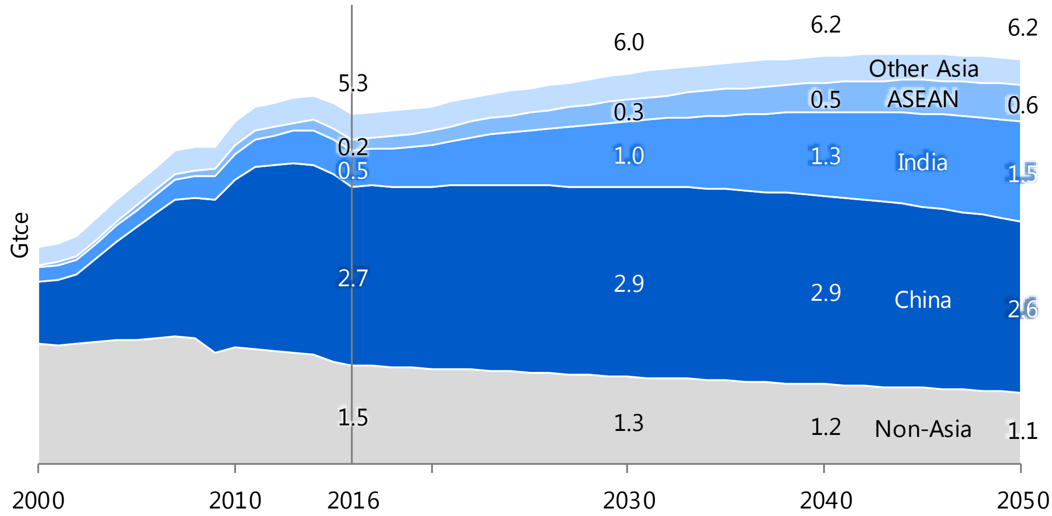
Changes in coal consumption have been overshadowed in recent years by relatively short-term factors. Consumption will not continue to decrease but will gradually increase to 6.0 billion tonnes of coal equivalent (Gtce[2]) in 2030 and 6.2 Mtce in 2040 (Figure 6). It will turn into a declining (slightly decreasing) trend after the mid-2040s. The situation, however, varies considerably from region to region. Coal consumption continues to decline in OECD, while China, the world's largest coal consumer, shows a slight increase until the mid-2030s before falling. On the other hand, India and ASEAN depend more on coal in 2050 than they do now because coal meets most of their vigorous projected energy

[1] Primary consumption. It includes neither processing gains nor biofuels.

[2] 1 tce = 0.7 toe

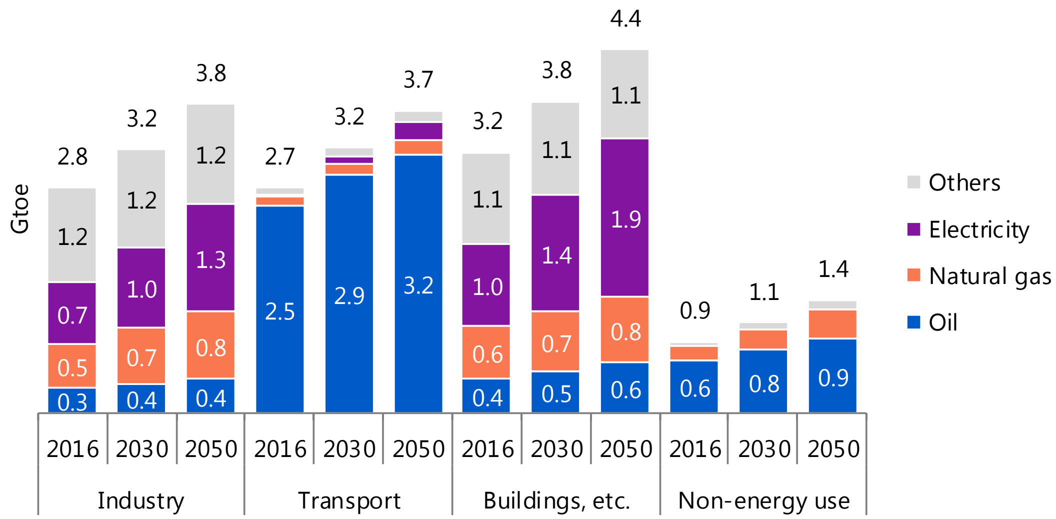
needs. Consequently, 82% of the global coal consumption will be concentrated in Asia in 2050.

Figure 6 | Primary consumption of coal [Reference Scenario]



Final energy consumption, which represents the actual consumption by end users, will reach 13.3 Gtoe by 2050, up 39% from the current 9.6 Gtoe (Figure 7). The increases are more or less 1 Gtoe in industry and transportation, and 1.3 Gtoe in the buildings sector. Most of these increments are derived from non-OECD consumption.

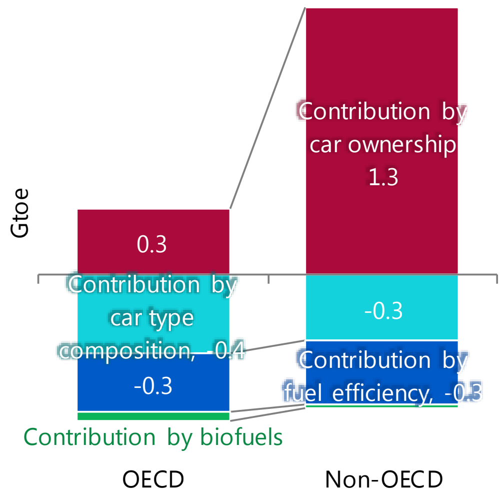
Figure 7 | World final energy consumption [Reference Scenario]



Oil will continue to be the most consumed energy source, but its share will fall from the current 41% to 38% in 2050. The road sector is the largest consumer of oil and the reduction of oil consumption attributable to electric vehicles and others is attracting attention. The fuel efficiency improvement of each type of car, however, is also effective in saving consumption at a scale equal to the change of car type composition (Figure 8).

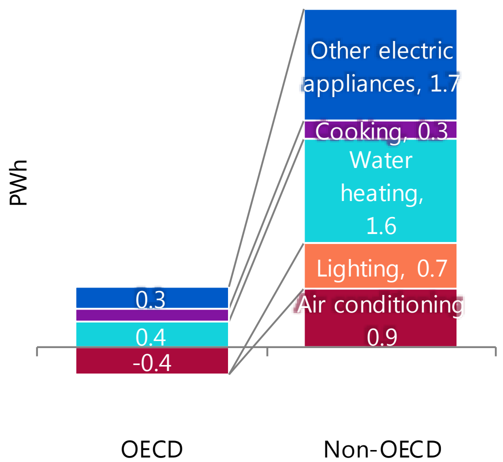
- Electricity is preferred at all stages of economic development in each country and region and will increase more than any other energy source. Its share of final energy consumption will rise from 19% to 26%. In the non-OECD household sector, which is key to the future, the demand for household appliances such as electric water heaters, air conditioners, lighting fixtures, and refrigerators will increase consumption, along with the expansion of electricity infrastructure (Figure 9).

Figure 8 | Contribution to changes in oil consumption in road sector [Reference Scenario, 2016-2050]



Note: The effect of switching from conventional internal combustion vehicles to hybrid vehicles is attributed not to fuel efficiency but to car type composition.

Figure 9 | Contribution to changes in electricity consumption in residential sector [Reference Scenario, 2016-2050]



- As electricity consumption increases, global electricity supply (power generation) will rapidly increase to almost double by 2050, (Figure 10). Therefore, for energy sources other than oil, the majority or most of the increase in primary consumption up to 2050 is attributed to power generation (Figure 11). In other words, what is used in power plants greatly affects the overall picture of energy consumption.

Figure 10 | Electricity generated [Reference Scenario]

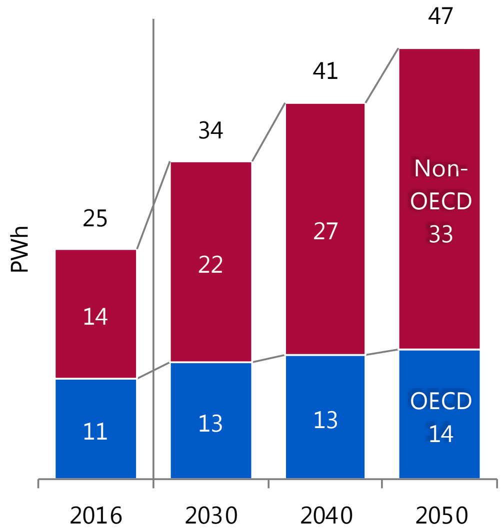
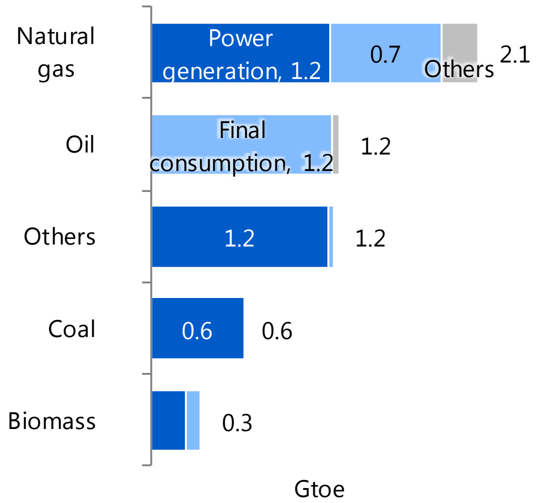


Figure 11 | Increase in world primary energy consumption [Reference Scenario]



Supply

- Through 2030, U.S. investment in exploration and development will be robust and shale oil (light tight oil) production will increase strongly (Figure 12). During the same period, crude oil production will also increase in Latin America, mainly as a result of the Brazilian pre-salt development. The Americas account for three quarters of the increase in global oil supplies, including Canada which increases production of unconventional oil. After that, non-OPEC's share of production will gradually decline due to a decline in U.S. shale oil production and a peak in production in Europe and Eurasia around 2030. From 2030 to 2050, OPEC will produce 90% of the increase in crude oil production. Countries such as Saudi Arabia, which has surplus capacity, and Iran and Iraq, which have the potential to increase production, will be the driving force.
- Crude oil trade between major regions will increase slightly from 42 Mb/d in 2017 to 43 Mb/d in 2030 (Figure 13). In the OECD, imports decline as consumption decreases and as production increases in North America. The need for additional imports due to consumption increases in emerging Asian economies, increases the overall trade volume. In Asia, supplies from the Middle East and Africa will account for 80% as of 2030, although supplies from North America and non-OECD Europe / Central Asia increase. Non-OECD Europe / Central Asia, Africa, the Middle East, and North America compete in supply to Europe, which imports decline. Non-OECD Europe / Central Asia and the Middle East will shift their export destinations to Asia, where demand is increasing. Exports of crude oil towards Europe from North America, where production is expanding, will increase.

Figure 12 | Crude oil production in selected regions [Reference Scenario]

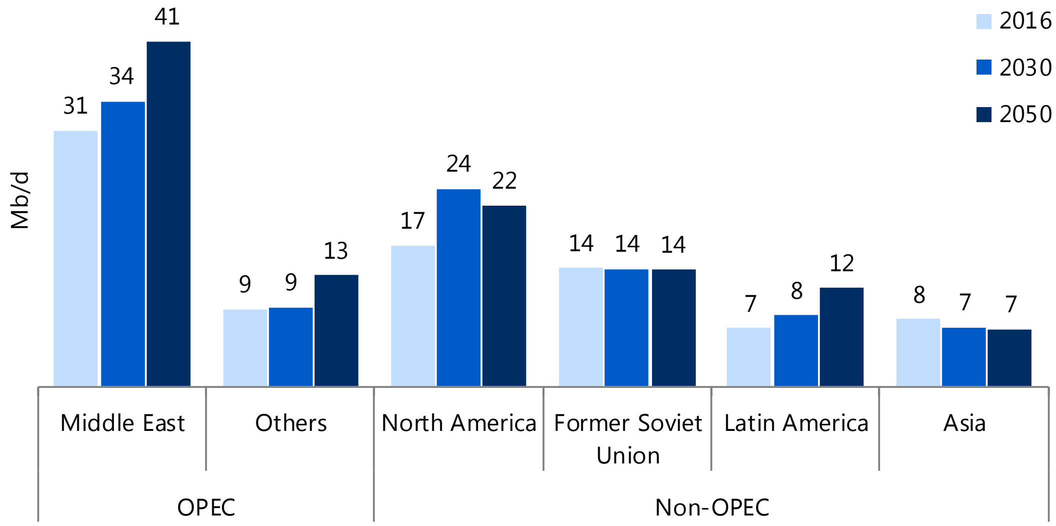
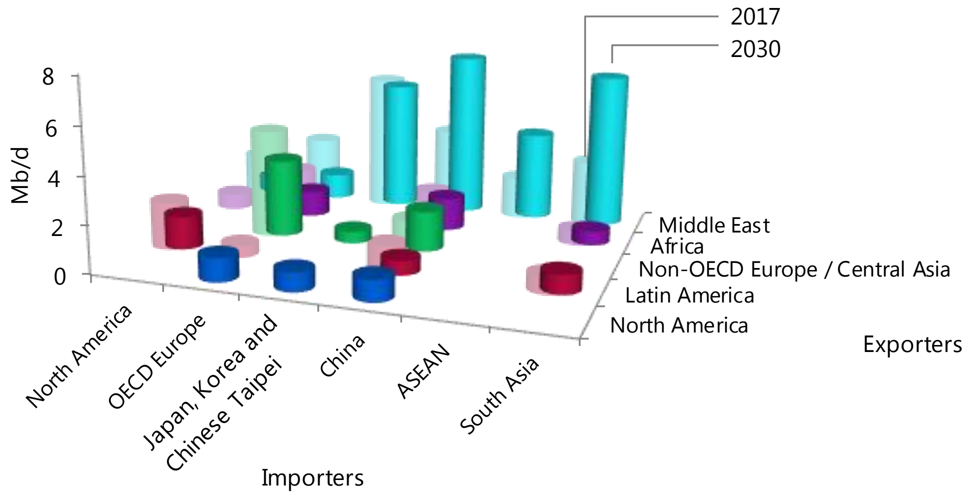


Figure 13 | Crude oil trade between selected regions [Reference Scenario, 2030]



With the recovery of oil prices since 2017, investments in natural gas development has started to increase and production will rise 1.7 times from 2016 to 2050 (Figure 14). In North America, the United States increases steadily production, mainly from Permian and Marcellus, while in Canada, the development of resources including shale gas is proceeding with the realisation of LNG projects on the West Coast. In the Middle East, which increases production the most after North America, an increase in consumption in the region combined with an increase in LNG exports will require additional production in the long run. Iran is currently forced to temporarily stagnate. In Russia, as demand for exports increases, the development of new gas fields along the Arctic coast and Eastern Siberia will be promoted. In Asia, gas developments will progress in China and India, where consumption is increasing and in Africa, new LNG projects in Mozambique, Tanzania and Senegal will increase production.

- Natural gas trade between major regions will increase from 631 billion cubic metres (Bcm) in 2017 to 800 Bcm in 2030. North America and the Middle East will increase exports the most. In North America, U.S. LNG exports will increase substantially, and Canada is planning new LNG exports. In the Middle East, Qatar is planning to increase its production capacity from the current 77 Mt to 100 Mt by 2024. Non-OECD Europe, including Russia, continues to be the largest exporter, expanding pipeline exports to Europe and increasing exports by pipeline to China and from new LNG export projects.
- The main players in LNG imports will spread from Japan and Korea, which have been the largest until now, to China, India and Europe (Figure 15). ASEAN, which has long been an exporter, is also rapidly expanding its imports due to increased consumption and resource depletion.

Figure 14 | Natural gas production in selected countries and regions [Reference Scenario]

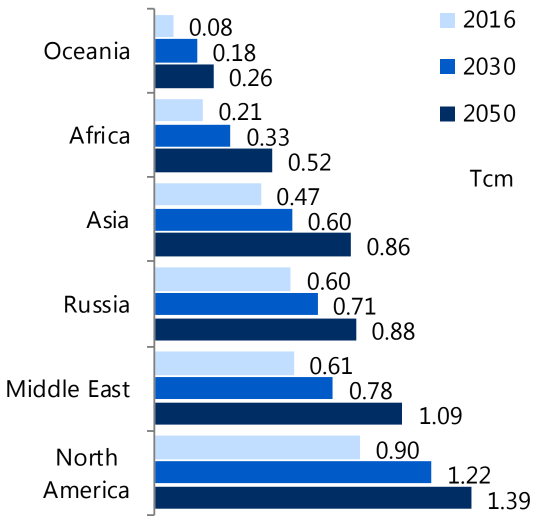
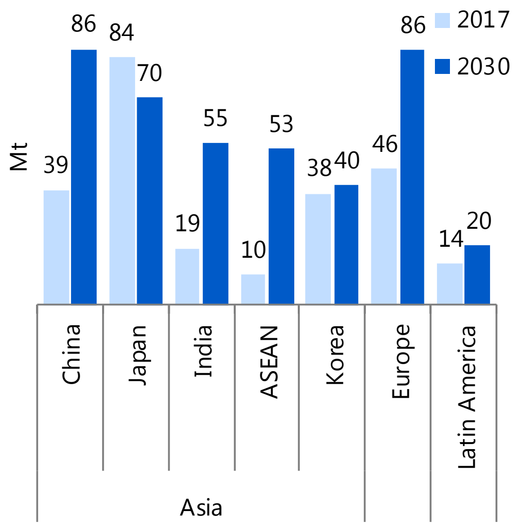


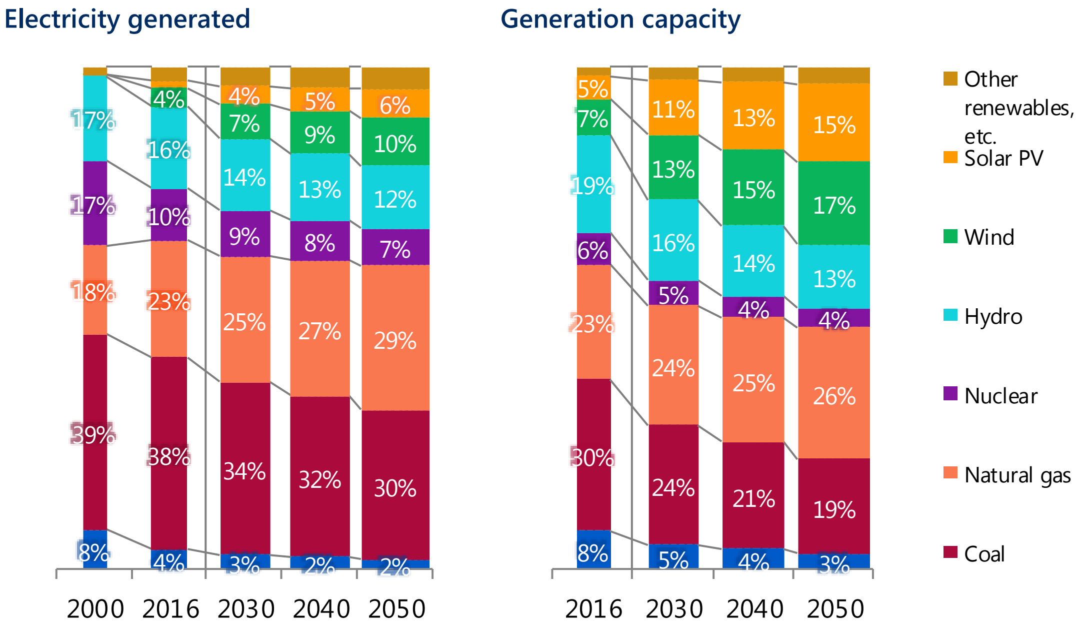
Figure 15 | LNG demand in selected countries and regions [Reference Scenario]



- Coal production will increase from 7.3 Gt in 2016 to 9.1 Gt in 2050 led by the increase in coal consumption mainly in Asia and by non-OECD, such as Latin America and Africa. The production growth will gradually slow down. The production of steam coal will increase 1.4 times from 5.5 Gt in 2016 to 7.4 Gt in 2050, mainly due to the increase in consumption for power generation, while the production of coking coal will decrease slightly.
- Although renewable energy is in the limelight in power generation, there is no change in the general framework of power generation mix, which continues to be centred on thermal power generation (Figure 16). Among thermal power generation, however, only natural gas, which offers high efficiency, low carbon dioxide (CO_2) emissions, and excellent load-

following properties, will gain share. Although coal is the largest power source and the amount of power generated continues to increase, its share will fall by 9% points (%p) due to a decline in the United States and Europe, and it will account for 30%, 1%p more than natural gas, in 2050.

Figure 16 | World power generation mix [Reference Scenario]



Note: The width of the bar is proportional to the total electricity generated.

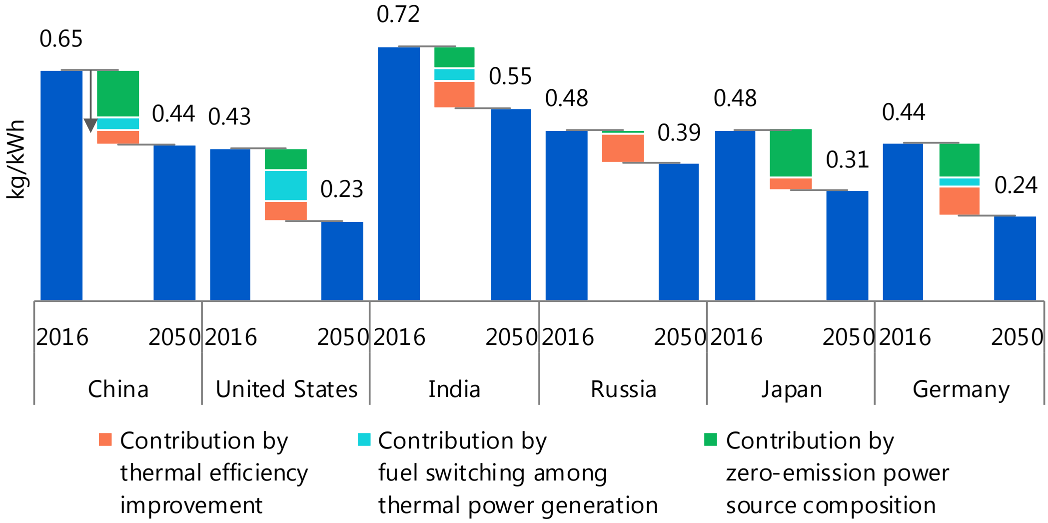
Note: The width of the bar is proportional to the total generating capacity.

- Due to changes in public opinion and increased construction costs following the accident at the Fukushima Daiichi Nuclear Power Station, it has become difficult for Japan, Korea, the United States and some countries in Europe to build nuclear power plants as planned. Many countries also reduced the use of nuclear energy because they are closing existing reactors. Other countries, however, will maintain a certain level of nuclear use from the viewpoint of maintaining and strengthening international competitiveness through stable energy supply, addressing climate change issues, and fostering their own nuclear industry. There are also several countries, including China, that are promoting the use of nuclear in the future. Global nuclear power generation capacity will increase from 406 GW in 2016 to 518 GW in 2050, and electricity generated by nuclear will increase 1.3 times. However, it will not catch up with the rapid increase in total power generation, and its share of power generation will fall by 3%p.

- There are great expectations for renewable energy such as solar photovoltaic (PV) and wind. Installed capacity of solar PV and wind power generation has been steadily increasing while costs have declined substantially, despite the effects of the reduction in support measures mainly in developed countries in Europe. Wind power generation capacity will increase fivefold from 465 GW in 2016 to 2,254 GW in 2050, and solar PV will expand sevenfold from 290 GW in 2016 to 2,110 GW in 2050. As the operation is influenced by natural conditions, however, the share of electricity generated by non-hydro renewable energy is only 15%, much smaller than its 32% share of generation capacity.

- In some countries and regions, increase in thermal power generation accounts for a large proportion, so the decline in the share of thermal power generation in the world, as a whole, will be only 5%p. Nevertheless, the carbon dioxide (CO_2) emission intensity per unit of power generation in each country and region will decrease. Major power producers also reduce their CO_2 emissions intensity through their own measures (Figure 17).

Figure 17 | Electricity carbon intensity in selected countries [Reference Scenario, 2050]



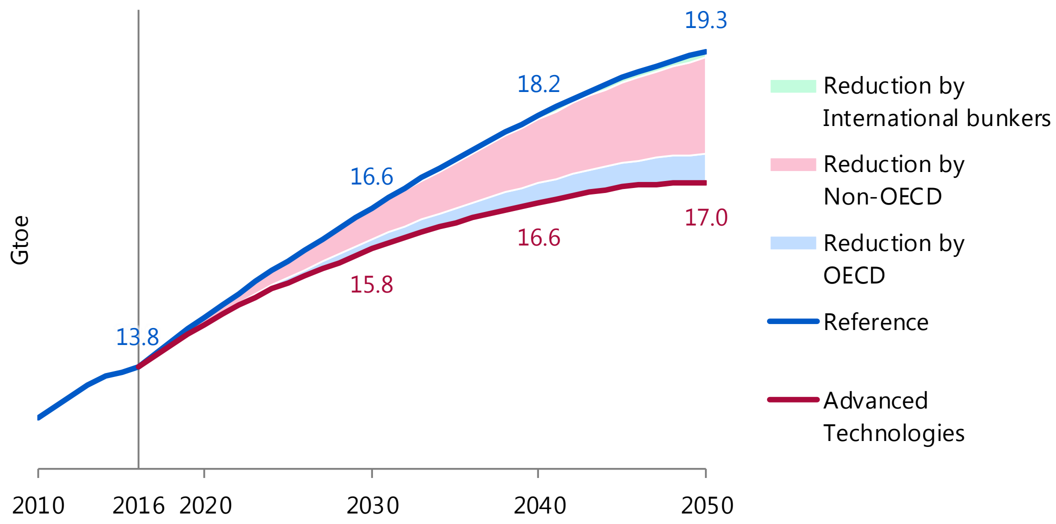
Note: Based on gross power generation.

Advanced Technologies Scenario

- The "Advanced Technologies Scenario" assumes that in order to secure a stable energy supply, combat climate change, and combat air pollution, energy conservation and low-carbon technologies will be deployed to the maximum extent in all countries of the world, taking into account their applicability and acceptability in the real world. Future consumption growth will be reduced by 41% relative to the Reference Scenario, and energy savings in 2050 will be 2.3 Gtoe, exceeding current U.S. consumption (Figure 18).

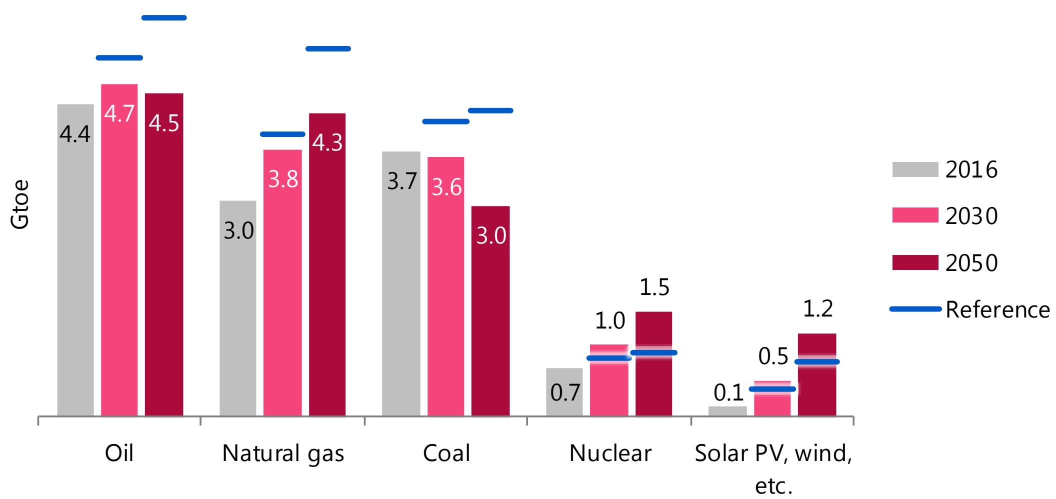
- 22% of the energy conservation required in 2050 to realise the Advanced Technologies Scenario will be achieved by 34 OECD countries. China and India, on the other hand, each will contribute 23% and 16% of the savings respectively and non-OECD will do 74%. The future of the world depends heavily on a wide range of deployment of energy conservation and low-carbon technologies in developing countries with potential for technological development.

Figure 18 | World primary energy consumption



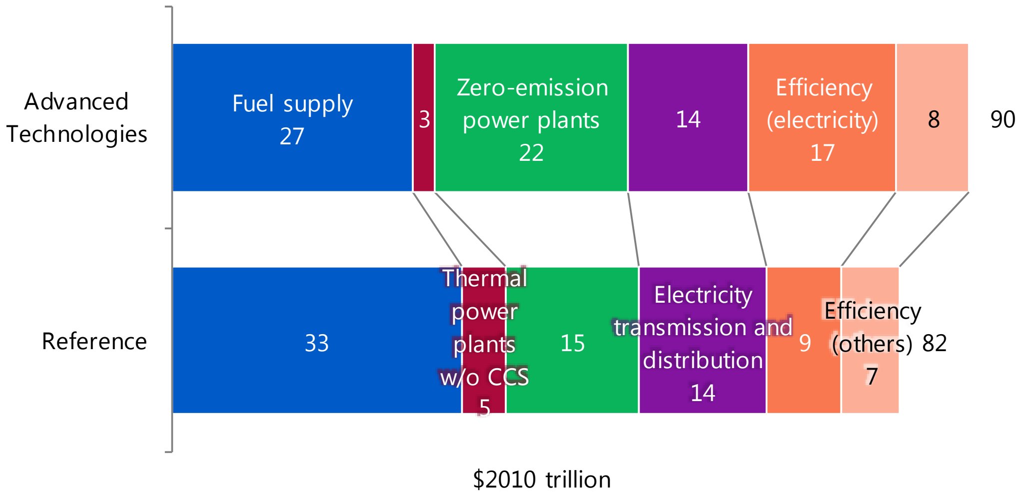
Fossil fuels will decrease by 3.3 Gtoe from the Reference Scenario in 2050 (Figure 19). As a result of reduced power consumption, improved power generation efficiency, and the effects of alternative energy sources, coal used primarily for power generation will decrease the most. Oil will peak after 2030 and then will be below the Reference scenario by 22 Mb/d in 2050. On the other hand, unlike coal and oil, natural gas will continue to increase under the Advanced Technologies Scenario until 2050. The increase is the largest in energy sources, as in the Reference Scenario. In non-fossil energy, nuclear is 0.6 Gtoe, and solar PV and wind, etc. is 0.4 Gtoe more than in the Reference Scenario. Consequently, fossil fuel's share will decline from 81% in 2016 to 69% in 2050 though the consumption amount will exceed current levels.

Figure 19 | World primary energy consumption [Advanced Technologies Scenario]



To realise this vision of energy supply, investments[3] totalling $90 trillion (in real terms in 2010) will be required by 2050 (Figure 20). Of that, $25 trillion will be for energy efficiency and fuel supply investment is $6 trillion less than for the Reference Scenario. Additional investment in Asia can be fully recovered by reducing fuel imports.

Figure 20 | World energy-related investments [cumulative from 2017 to 2050]

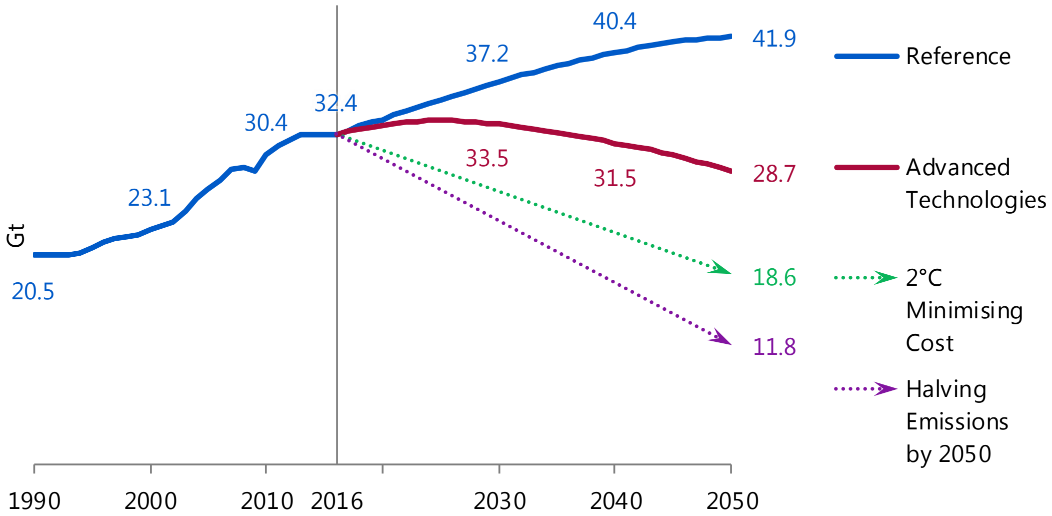


The world's energy-related CO_2 emissions will peak in the mid-2020s and begin to gradually decline, reaching 28.7 Gt in 2050, down by 1.7 Gt, or 6% from 2010[4] (Figure 21). A reduction of 13.2 Gt from the Reference Scenario is equivalent to 43% of the world's emissions in 2010, and the cumulative reduction of 206 Gt by 2050 is equivalent to 6.8 years of the world's current emissions. By region, OECD's CO_2 emissions are reduced by 49% in 2050 from 2010 while emissions from Non-OECD will increase by 23% from 2010. Emissions from Non-OECD will decrease after peaking in the mid-2030s .

[3] An investment, not an unprofitable cost or loss. Many of these investments are expected to be fully recovered in a functioning market environment. However, if short-termism prevails in the market, energy investments that require a long payback period are less likely to attract sufficient funds and the risk of not making the necessary investments increases.

[4] At the G7 Elmau Summit in 2015, "sharing with all parties to the UNFCCC the upper end of the latest IPCC recommendation of 40 to 70 % reductions by 2050 compared to 2010" was supported. However, at the 2018 G7 summit in Charlevoix, "Canada, France, Germany, Italy, Japan, the United Kingdom and the European Union reaffirm their strong commitment to implement the Paris Agreement, through ambitious climate action; in particular through reducing emissions…" without making any quantitative reference. In addition, the United States did not join.

Figure 21 | World energy-related CO_2 emissions



The Halving Emissions by 2050 Path is path represents an emission path in the RCP2.6 scenario summarised in the fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC).

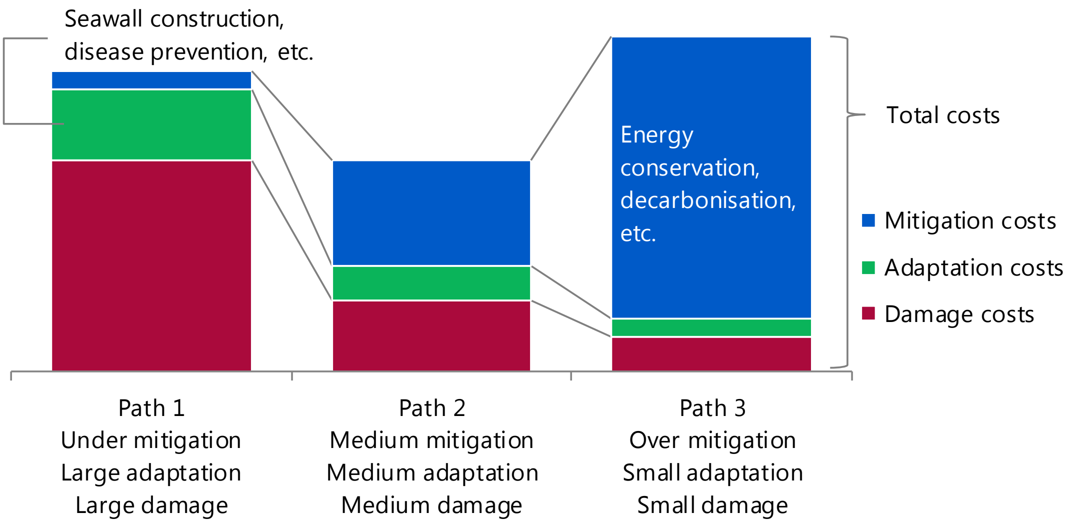
Addressing climate change issues – republication of IEEJ Outlook 2018

- The climate change issue is a long-term challenge that will involve a wide range of activities over numerous generations. When and how specific measures should be taken and what measures should be implemented must be considered carefully. From the viewpoint of balance and sustainability, a combination of measures to minimise the total costs covering mitigation, adaptation and damage is evaluated (Figure 22). For example, an attempt to spend $1,000 on cutting emissions and building seawalls to prevent $100 in damage would be very difficult to justify and risk failure.

- In the "Minimising Cost Path" in which cumulative total cost is minimised, energy-related CO_2 emissions in 2050 are reduced to as much as in the Advanced Technologies Scenario. It, however, is not necessary to cut by half the emissions from today (Figure 23). GHG emissions continue to decline moderately after 2050 and fall by 52% from today in 2100. The atmospheric GHG concentration[5] will continue to rise slowly until around 2100 and fall to 550 ppm in 2150. Temperatures increase by 2.4°C and 2.6°C in 2100 and in 2150, respectively, compared to the latter half of the 19th century. That is, the Minimising Cost Path is different from a path of achieving the very ambitious long-term goals of the Paris Agreement.

[5] CO_2 equivalent, including aerosols, etc.

Figure 22 | Illustration of the total costs of mitigation, adaptation and damage



- It, however, is dependent on assumptions. For example, although the Minimising Cost Path delays mitigation measures, the temperature rise will still be about 2°C if the climate sensitivity[6] is 1.9°C instead of 3.0°C. A simple calculation results in a difference of about 0.5°C in the temperature of 2200 due to the difference in climate sensitivity of 1°C. In addition, if the average discount rate of the period until 2300 is 1.1%, instead of 2.5%[7], future costs would be higher, so the path for earlier mitigation would be considered as optimal, with a temperature rise of 2°C around 2100 and then decreasing. By simple calculation, a difference of 1% point of the discount rate results in a temperature difference of about 0.5°C in 2200.

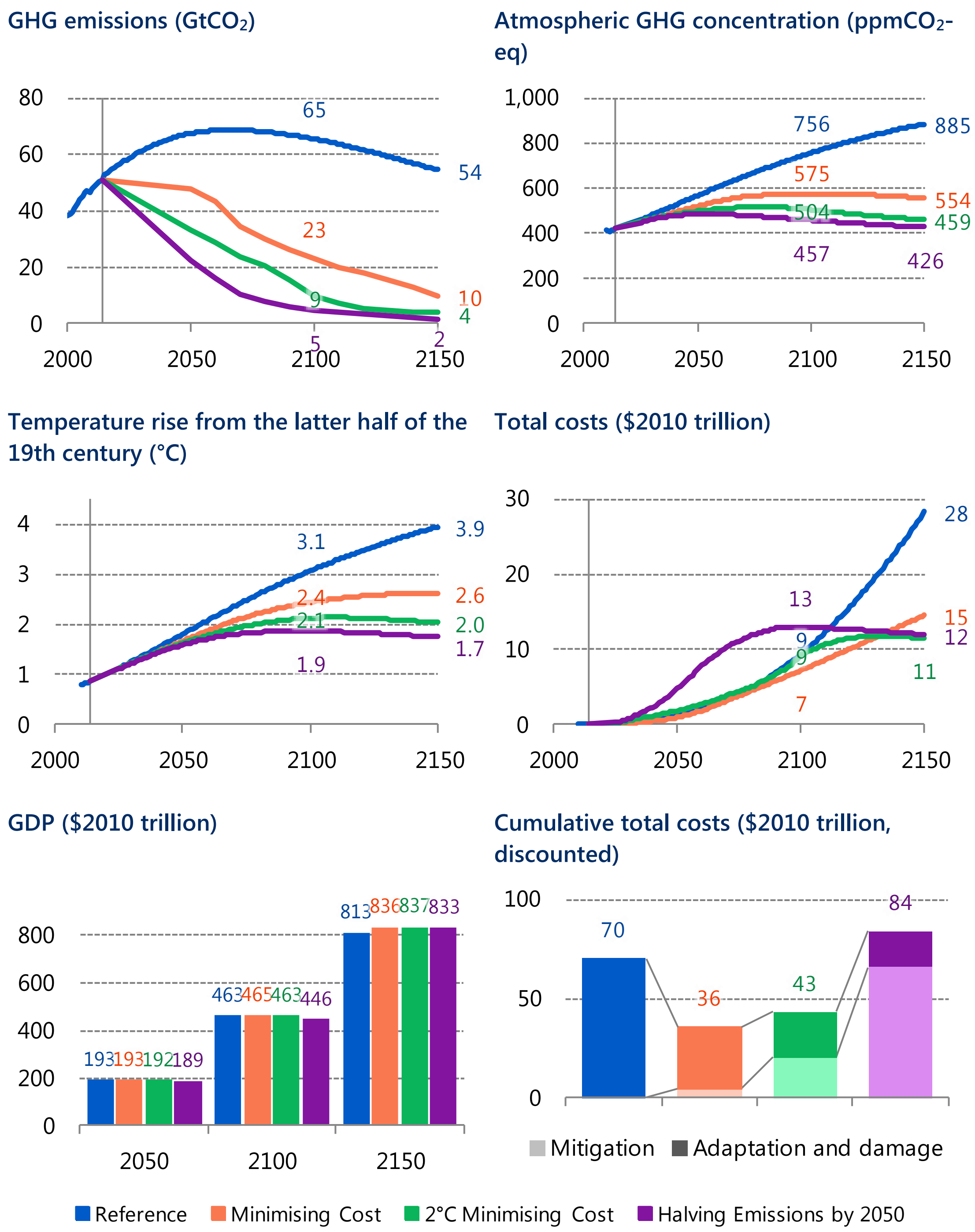
- It is also useful to consider a path that is stronger to curb the temperature rise than the abovementioned Minimising Cost Path, respecting the "2°C Target" in international political and negotiation arenas. For example, in order to keep the cumulative total cost as small as possible and to reduce the temperature rise range in 2150 to 2°C, additional reductions are required to the Minimising Cost Path. GHG emissions under this "2°C Minimising Cost Path" decrease by 31% and by 80% in 2050 and in 2100, respectively, compared to 2010.

- The development and diffusion of innovative technologies is essential for the realisation of the 2°C Minimising Cost Path. All innovative technologies, including other options, have challenges in development and social acceptability today. International cooperation is important to overcome these challenges for individual technology development.

[6] Average temperature increase when the atmospheric GHG concentration as CO_2 equivalent concentration is doubled (°C).

[7] The average of 2.5% is equivalent to the pure time preference rate $\delta = 0.5\%$ in the Ramsey rule and the elasticity of the marginal utility of consumption $\eta = 2$. The average of 1.1% is $\delta = 0.1\%$ and $\eta = 1$.

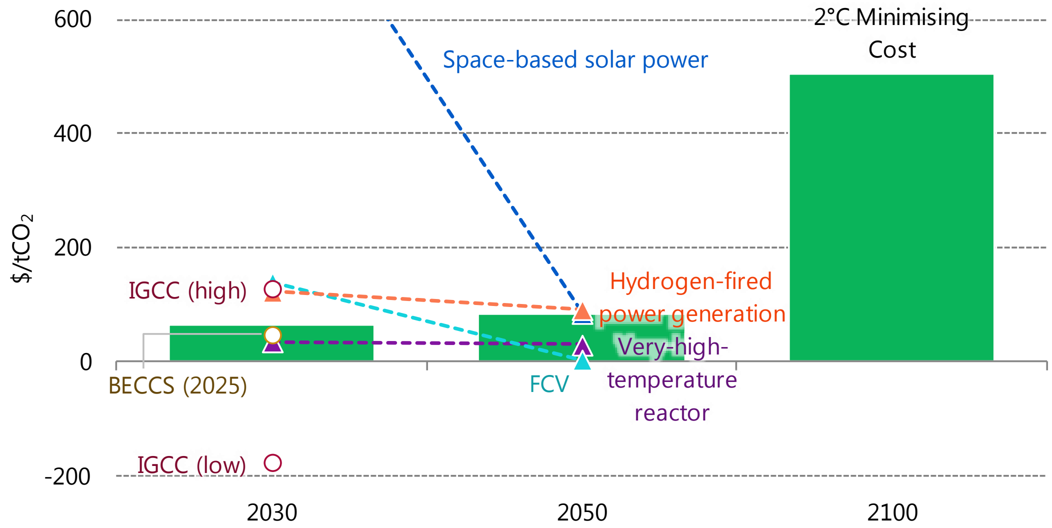
Figure 23 | Ultra long-term paths



Note: Atmospheric GHG concentrations include aerosols, etc. Cumulative total cost is 2015 to 2500.

In addition, the costs of technologies must be sufficiently lowered. The highest implicit CO_2 reduction costs (in 2010 prices) for the 2°C Minimising Cost Path are \$85/tCO_2 in 2050 and \$503/tCO_2 in 2100 (Figure 24). The Minimising Cost Path provided by the principle of reducing cumulative total cost will not introduce a technology unless its cost falls below these CO_2 reduction costs. In addition, unless it is cheaper than other competitive technologies, the technology will not be selected economically if the potential for introducing competitive technology is not limited. Innovative technologies also need "innovative" ways to reduce their costs. The target costs for those technologies, such as BECCS, hydrogen-fired power generation, FCV, very-high-temperature reactor, and space-based solar power are almost within the range of the CO_2 reduction costs; the 2°C Target can be achieved with the use of these technologies.

Figure 24 | CO_2 reduction costs



Note: The 2°C Minimising Cost Path is the highest CO_2 reduction cost among the technologies adopted at each time of the Path (carbon price) and in 2010 prices. The assumptions and ambition of the goal and estimates are different in each technology.
Key assumptions for calculation:
[Very-high-temperature reactor] With reference to the Nuclear Science and Technology Commission "Development of future research and development related to the very-high-temperature reactor technology (draft)," the construction cost of a 0.3 GW reactor is assumed at about \$500 million.
[Integrated coal gasification combined cycle (IGCC)] With reference to OECD/NEA "Projected Costs of Generating Electricity, 2015 Edition," the construction cost is assumed \$1,200/kW - \$2,900/kW and power generation efficiency is assumed 50% - 52%.
[Fuel cell vehicle (FCV)] With reference to the Hydrogen and Fuel Cell Strategy Council "Hydrogen and Fuel Cell Strategy Roadmap," assumed that vehicle price in 2050 is \$25,000 (same as conventional vehicle), fuel economy is 115 km/kg (fuel efficiency of 31 km/Lge) and hydrogen retail price is \$0.5/Nm^3.
[Hydrogen-fired power generation] With reference to the Hydrogen and Fuel Cell Strategy Council "Hydrogen and Fuel Cell Strategy Roadmap" and IEA "Technology Roadmap: Hydrogen and Fuel Cells," assumed that plant delivery price of hydrogen in 2050 is \$0.15/Nm^3, construction cost is \$1,200/kW, and power generation efficiency is 57%.
[Space-based solar power] With reference to the Space System Development Promotion Organization "Integrated Space Solar Power Generation System 2006 Model Research and Development Roadmap, Revised version 2016," \$100/MWh as the target unit price for power generation in 2050 is used.
[Biomass power generation with CCS (BECCS)] With reference to IRENA "Renewable Power Generation Costs in 2014" and the IPCC "Special Report on CCS," estimated based on power generation cost of \$130/MWh and CO_2 recovery and storage cost of \$70/tCO_2.

Risk and impact of energy supply disruptions

Oil supply disruptions

Oil supply disruptions have been at the heart of the traditional energy security debate. Various supply disruptions have occurred at each stage of production, transport, and domestic supply due to accidents, failures, natural disasters, or structural factors affecting society and the economy as a whole. And the risks remain present.

Table 1 | Oil supply disruption risks and examples

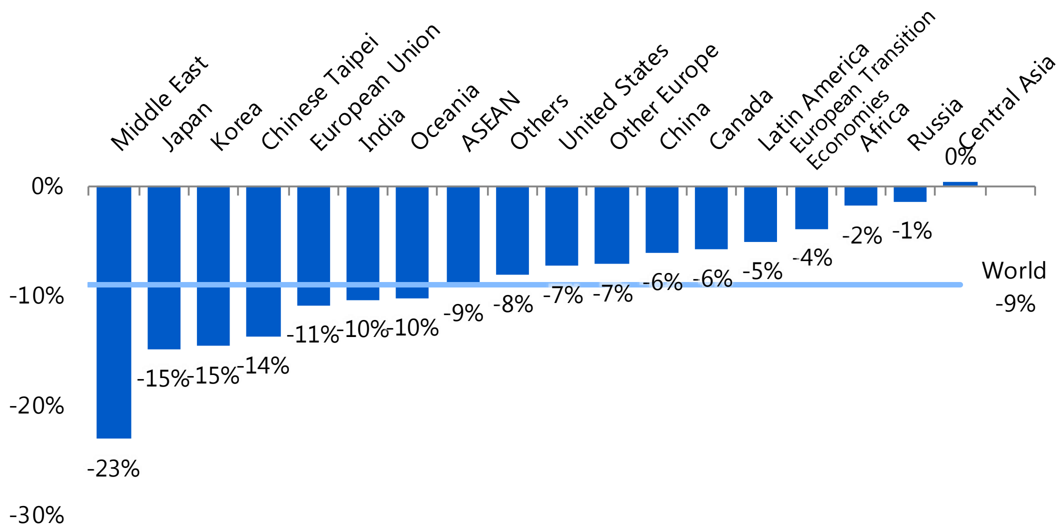
	Risks	Examples
Production	Destruction or shutdown of production facilities due to unanticipated events such as accidents, failures or natural disasters Destruction of production facilities and suspension of operations due to political upheavals and terrorism Halting exports by political will or strategy	1973: OAPEC countries imposed an embargo on exports to the United States and the Netherlands. 2005: Hurricanes shut down oil production facilities in the U.S. Gulf Coast 2018: Exports of crude oil from Libya were partially reduced because of suspension of production and the blockade of ports due to internal strife.
Transport	Destruction or shutdown of facilities due to unanticipated events such as accidents, failures or natural disasters Destruction or suspension of transportation (ships, pipelines, etc.) by terrorism or piracy Interruption of transport routes by political will, strategy and military action	1984 - 1988: The "tanker war" by Iran and Iraq 2011: Destruction of gas pipelines from Egypt to Israel by terrorist attacks 2018: Attacks on crude oil tankers by Yemeni militants
Domestic supply	Destruction or shutdown of supply facilities due to unpredictable events such as accidents, failures or natural disasters Destruction of supply facilities and suspension of operations due to terrorism	2011: Oil supply suspension due to the damage of oil refineries and oil depots and the destruction of ports, railways and roads caused by the Great East Japan Earthquake

Most recently, there are concerns that the resumption of sanctions on Iran following the U.S. withdrawal from the Iranian nuclear agreement could affect oil supplies. According to our scenario analysis, if Iran's crude oil exports (approximately 2.5 Mb/d) completely disappear, the oil price could rise due to the tightening of OPEC surplus production capacity. On the other hand, under a scenario of intensifying trade friction originating in the United States, the global economic slowdown could lead to an easing of oil supply and demand and a decline in oil prices.

The disruption of oil supply has major impacts. If crude oil production in the Middle East falls by 10 Mb/d and other countries or regions cannot increase their production, the global economy would shrink by 9% (Figure 25). Except for the Middle East, the epicentre of supply disruptions, Japan, Korea and Chinese Taipei would suffer the most damage.

Other net oil-exporting countries and regions are not immune to adverse effects, and no country or region other than Central Asia can obtain absolute gain.

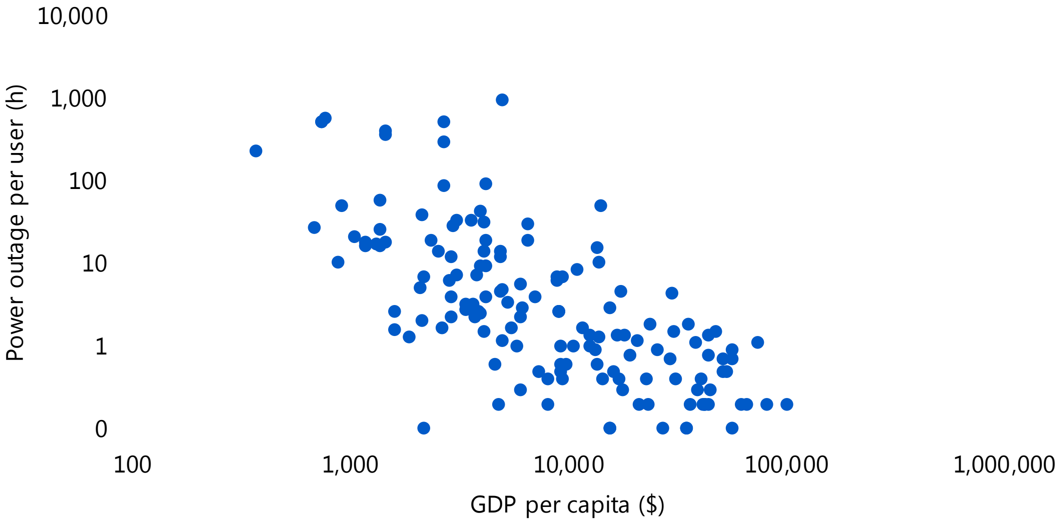
Figure 25 | Impact of a 10 Mb/d decline in crude oil production in the Middle East on real GDP



Electricity supply disruptions

- The electricity supply disruption appears in the form of a power outage. Internationally, power outage varies widely by region, with some low-income countries experiencing more than 10% power outage per year. In developed countries, the annual power outage per user is often less than one hour, and in recent years, it is sometimes limited to several minutes mainly in large cities due to the progress of automation of transmission and distribution. Large-scale natural disasters often result in power outages but supply to most consumers is restored within a few days.
- Although the quality of electric power supply demanded by consumers has improved due to progress in information and communication technology, (1) the dependence on specific energy sources has increased, (2) the duck curve of net load due to the expansion of solar PV power generation, (3) the shutdown of power plants due to economic efficiency, and (4) cyber attacks are all attracting attention as new risks.
- The blackout that occurred throughout Hokkaido in September 2018, following the 2018 Hokkaido Eastern Iburi Earthquake, reminded us of the importance of electricity in people's lives and economic activities. Analysis of the cause is being carried out by the Organization for Cross-regional Coordination of Transmission Operators, Japan and based on this experience, discussions on how to enhance the stability of electricity supply are expected to develop.

Figure 26 | Income level and power outage [2015]



Source: World Bank "Doing Business database" and "World Bank Open Data"

Comparison of oil and electricity

- Compared with oil, which has traditionally been the subject of supply disruptions, the geographical extent of electricity power supply disruptions is narrow. In the case of oil with a well-developed futures market, the impact of a crisis would spread to every corner of the world economy in a short period of time, not only in the form of limits on physical supply but also in the form of soaring prices in the international market. In the case of electricity, however, the impact is often limited to the country or region.
- Diversification, redundancy, and decentralisation are common to both supply failures. In the case of oil, they are diversification of import partners and routes, geographical distribution of oil refineries and oil depots, and redundancy of supply networks. In the case of electricity, they are diversification of fuel types at power plants, geographical distribution, and redundancy of transmission and distribution networks. This reduces the risk of problems and enhances the ability to respond when they occur. Diversification and redundancy of infrastructure, however, mean increased costs, so a difficult balance between the two propositions of enhanced security and economic rationality is needed. With regard to oil, it is also important to support the diversification and stabilisation of the economies of oil-producing countries, particularly in the Middle East.
- For oil, there are stockpiles for emergency response in many cases, and among the member countries of the International Energy Agency, a system has been established to respond internationally in a coordinated manner, thus ensuring the ability to respond to emergencies. In the case of electricity, however, there is no equivalent to oil stockpiling because the current technology cannot economically store electricity on a large scale for a long period of time. In addition, the system is not sufficiently guaranteed to ensure the necessary reserve power generation capacity in the event of supply failure. For developed countries that have completed the liberalisation of their industry, it is difficult to maintain

the kind of reserve power that previously depended on the voluntary judgment of the major utilities. A system that ensures proper reserve power needs be developed.

On the other hand, in the field of electricity, technological innovations such as the improvement of supply and demand prediction accuracy by artificial intelligence (AI), the management of demand by utilising the Internet of Things (IoT), and the adjustment of supply and demand in combination with batteries for electric vehicles are making it possible to implement stable supply measures previously unimaginable. It is desirable to establish appropriate security systems in the electricity market, including measures against cyber attacks that are becoming a real threat.

Table 2 | Features of oil and electricity supply disruptions

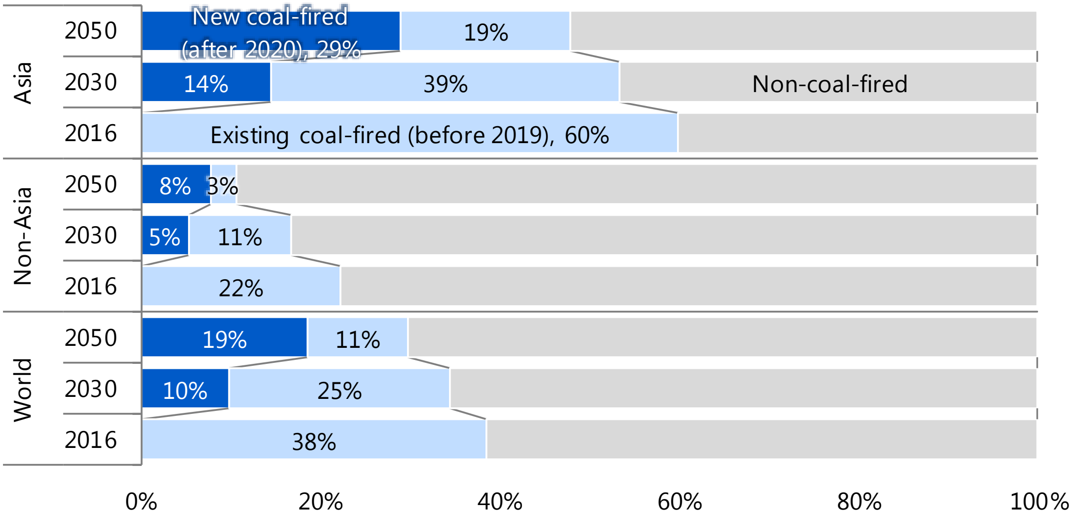
	Oil	Electricity
Geographical spread of the impact	Wider	Limited
Demand substitution	More elastic	Less elastic
Response to supply disruptions	Diversification of import partner countries / routes	Diversification of power generation fuels
	Geographical distribution of domestic facilities	Geographical distribution of power generation facilities
	Redundancy of domestic supply network	Redundancy of transmission and distribution networks
	Support for economic stabilisation in oil-producing countries	Reserve power generation capacity
	Stockpiling	

Note: Assessment of the geographic spread of impacts and demand substitution represents the relative relationship between oil and electricity.

Impact of banning the construction of new coal-fired power plants

Global energy-related CO_2 emissions will increase by 10 Gt by 2050 under the Reference Scenario, with the majority of this increase attributable to direct emissions from the power generation sector. Against such backdrop, there have been increasingly harsh views arguing against coal-fired power generation in recent years. A shift away from coal would represent a major transition from the present situation, especially in Asia, and there are many problems that would need to be overcome. These problems are set aside for now, as we simulate a hypothetical case in which all new coal-fired power plants would be banned from construction after 2020 without exception (No New Coal-fired Power Plant Case).

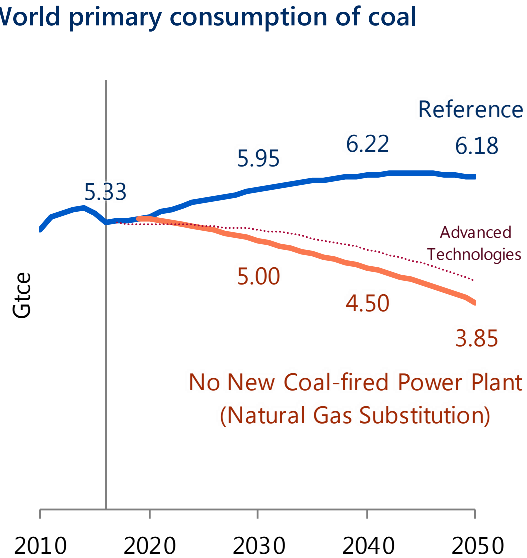
Figure 27 | Power generation mix [Reference Scenario]

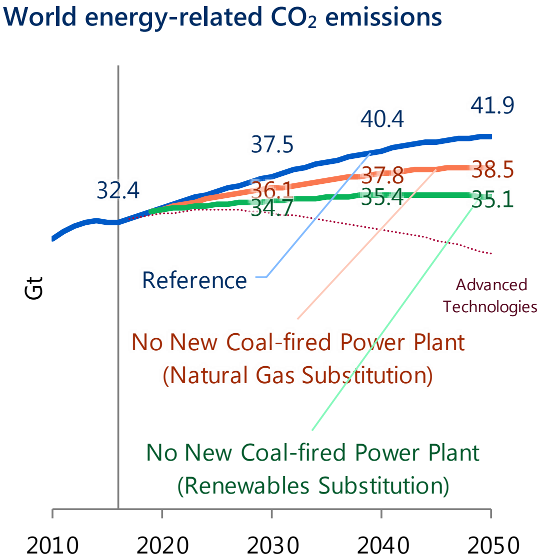


Effects of banning the construction of new coal-fired power plants

The replacement of 1.6 TW of new coal-fired power plants that were to be built after 2020, most of them in Asia, would reduce world primary coal consumption to about 3.8 Gtce in 2050, or 70% of the current consumption level of 5.3 Gtce (Figure 28). The reduction of 2.3 Gtce from the Reference Scenario exceeds the reduction in the Advanced Technologies Scenario and is comparable to the current production of China, the world's largest coal producing / consuming country.

Figure 28 | Benefits of banning the construction of new coal-fired power plants





- Global energy-related CO_2 emissions increase to 42 Gt by 2050 under the Reference Scenario. If all new coal-fired power plants are substituted by natural gas, the emissions will be reduced by slightly more than 3 Gt and if they are replaced by solar PV and wind power generation, the reduction reaches 7 Gt, equivalent to the combined emissions from the world's second and third largest emitters, the United States and India. The remaining emissions of 35 Gt are still above current levels showing that although a shift away from coal-fired power generation is attracting attention, it is far from sufficient to solve the problem of climate change alone.

Inevitable side effects – higher prices, lower self-sufficiency, etc.

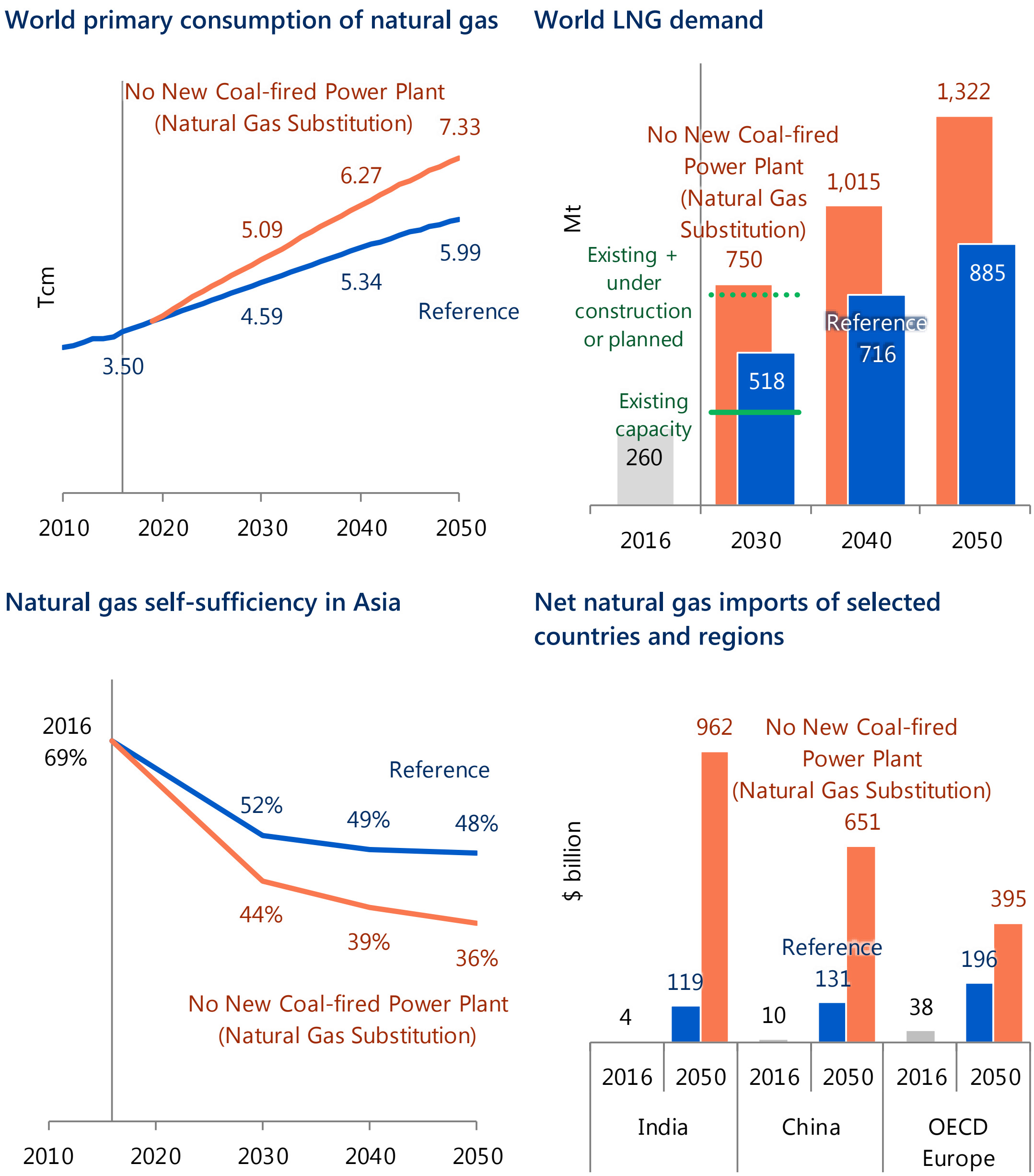
- If natural gas-fired power plants are built instead of coal-fired power plants, the world's primary consumption of natural gas will reach 7.3 trillion m^3 (Tcm) in 2050 (Figure 29). The additional consumption of 1.3 Tcm from the Reference Scenario is enormous, equivalent to the sum of the current production of the United States and Russia (38% share of the world production). To meet such dramatically expanding consumption, all possible resources need to be developed – including those that are technically difficult, such as deep water and the Arctic Ocean.

- It is essential to expand natural gas trade, particularly LNG trade, because Asia is the main source of the consumption growth, while the Middle East, non-OECD Europe and North America are the main sources of the production growth. The amount of LNG trade required in 2030 will be 750 Mt, which is 2.9 times the current level. There will be a shortfall of liquefaction plants to meet such demand if only the relatively confirmed development plans (around 720 Mt) come into operations.

- Even if these rapid increases in production and trade can be realised, Asia will face energy security problems. In other words, Asia, which is poor in natural gas resources, will be forced to rely on imports from outside the region. The self-sufficiency rate of natural gas will consequently plunge from the current 69% to 36% in 2050, nearly half the current level.

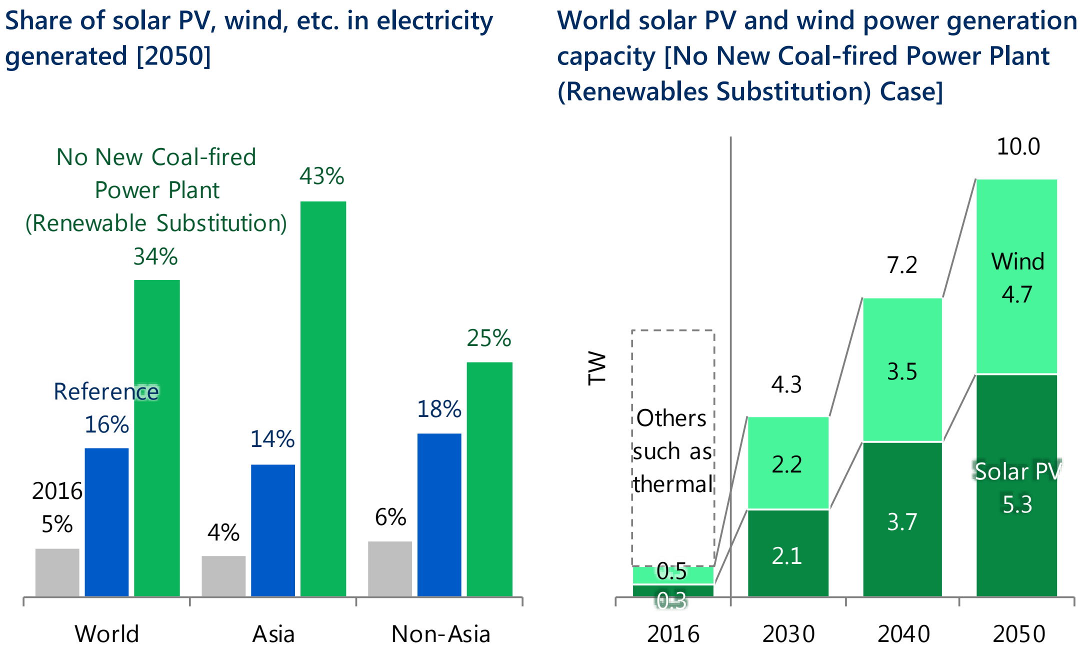
- Although the increase in natural gas consumption is significant in Asia, its impact will not be limited to Asia. Rising natural gas prices due to a large increase in consumption will affect the entire world. In 2050, we assume that the price will jump to $15/MBtu (in real terms in 2017) in the United States, where exports will increase most, $18/MBtu in Europe, and $20/MBtu in Japan. As a result, even the OECD Europe, which will have a smaller upward swing in consumption of natural gas for power generation, will increase its net natural gas imports to $400 billion.

Figure 29 | Impact on natural gas of banning the construction of new coal-fired power plants



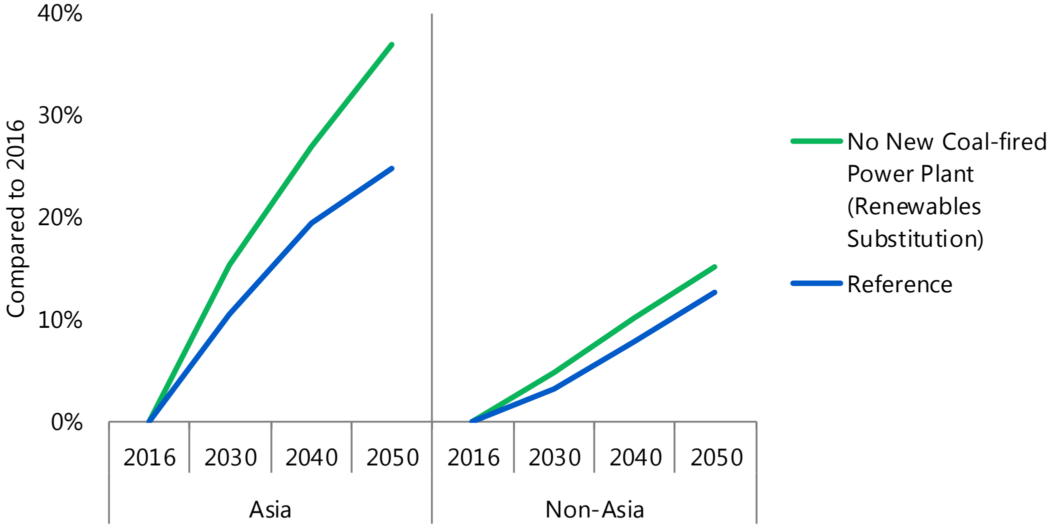
Alternatively, if the reduction in coal-fired power generation is compensated for by solar PV and wind power generation, the share of solar PV, wind, etc. in power generation in 2050 will reach 34% in the world and 43% in Asia (Figure 30). To replace 1.6 TW of coal-fired power generation capacity would require at least 10.0 TW of solar PV and wind power generation capacity in the world – 1.6 times the current combined capacity of thermal, renewable and nuclear power – and 7.2 TW in Asia, assuming favourable conditions exist. Sustainable measures to promote the mass adoption of renewable energy are essential.

Figure 30 | Impact on solar PV and wind power generation of banning the construction of new coal-fired power plants



Drastic measures are needed to maintain a stable supply of electricity while introducing large amounts of intermittent renewable power sources such as solar PV and wind. They require the introduction of equipment and fundamental changes in the operating system, driving up electricity costs (Figure 31). In addition, the sources of economic incentives to encourage the introduction of large quantities of renewable power – a burden that is currently a problem in many countries – can spur higher electricity costs. Sufficient attention should be paid to electricity security so as not to induce problems such as energy poverty and competitive disadvantage.

Figure 31 | Impact on electricity costs of banning the construction of new coal-fired power plants «indicative»



Notes: Including costs for power generation facilities, fuel costs and grid-level system costs. Based on real prices in 2010. The plant costs of renewable power generation are expected to decrease over 2050. The reduction rate (approximately 30% for solar PV and 10% for wind by 2050) was based on IEA "World Energy Outlook 2016." Cost reduction by the addition of the introduction quantity from the Reference Scenario is not considered. Grid-level system costs are set with reference to OECD/NEA "The Full Costs of Electricity Provision" (2018). Regional characteristics are not considered.

Victoria concordia crescit (Victory comes from harmony)

- Low-carbonisation of power generation is an essential part of the measures for climate change. Countries and regions that can immediately abolish coal-fired power generation should steadily promote this approach. On the other hand, there are high hurdles to overcome in order to develop the same movement in Asia. Developed countries outside Asia, which are promoting a shift from coal-fired power generation around the world, must also be prepared to provide financial and technical support for the energy transition in developing Asia.
- Countries and regions that currently face difficulties to shift from coal-fired power generation or have other appropriate measures to reduce CO_2 emissions cannot avoid calmly assessing their priorities. The objection is to address climate change and shifting from coal-fired power generation is only one of the possible means to achieve the objection. Of course, even in those countries and regions, low-efficiency coal-fired power plants must quickly be replaced with high-efficiency plants. Efforts must also be made to create an environment in which the dependence on coal-fired power generation can be reduced.
- On a larger scale, it should be reminded that climate change is one of humanity's great challenges, but not the only one. When taking actions, including those for coal-fired power generation, it is essential to prepare measures to reduce the adverse side effects. A thorough consideration of the realities of each country and region combined with a

realistic path based on harmonised judgment will lead to a true approach to the global challenge of sustainable development.

Part Ⅰ

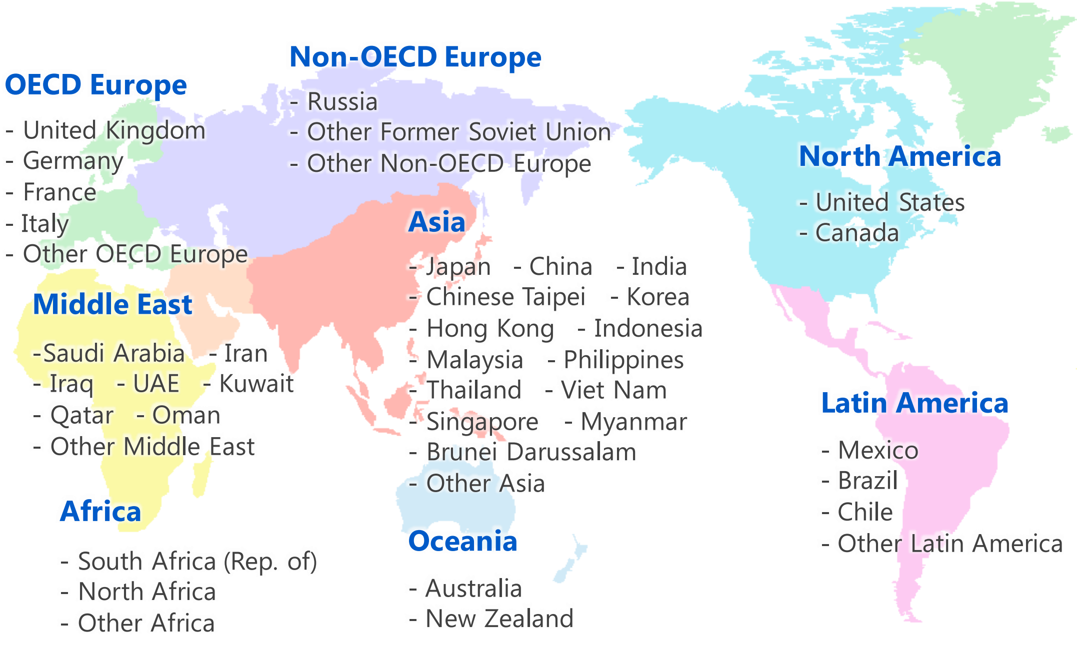
World and Asia energy supply / demand outlook

1. Major assumptions

1.1 Model and scenarios

We used a quantitative analysis model, with an econometric approach adopted as the core, to develop an energy outlook and assess energy supply and demand in the world through 2050. The model, based on the energy balance tables of the International Energy Agency (IEA), covers various economic indicators as well as population, vehicle ownership, basic materials production and other energy-related data collected for modelling. We divided the world into 42 regions and international bunkers, as indicated in Figure 1-1 and built a detailed supply and demand analysis model for each.

Figure 1-1 | Geographical coverage



We developed the following two main scenarios for the projection.

Reference Scenario

This is the core scenario for this Outlook. For this scenario, an outlook is developed according to past trends as well as the energy and environment policies that have been in place so far. Policies expected through traditional and conventional ways of thinking are incorporated into this scenario. This does not mean that policies or technologies may be fixed as the present ones. On the other hand, we assume that no aggressive energy conservation or low-carbon policies deviating from the past trends will be adopted.

Advanced Technologies Scenario

In this scenario, all countries in the world are assumed to strongly implement energy and environment policies contributing to a secure and stable energy supply and enhancing climate change countermeasures. These policies' effects are assumed to be successfully maximised. Specifically, our projection is based on the assumption that advanced technologies for the energy supply and demand sides as given in Figure 1-2 will be introduced as much as possible, with their application opportunities and acceptability taken into account.

Figure 1-2 | Technology introduction assumptions for the Advanced Technologies Scenario

Introducing and enhancing environmental regulations and national targets

Environment tax, emissions trading, RPS, subsidy, FIT, efficiency standards, automobile fuel efficiency standard, low carbon fuel standard, energy efficiency labelling, national targets, etc.

Promoting technology development and international technology cooperation

R&D investment expansion, international cooperation on energy efficient technology (steelmaking, cement and other areas), support for establishing energy efficiency standards, etc.

Demand side technologies

■ Industry

Under sectoral and other approaches, best available technologies on industrial processes (for steelmaking, cement, paper-pulp and oil refining) will be deployed globally.

■ Transport

Clean energy vehicles (highly fuel efficient vehicles, hybrid vehicles, plug-in hybrid vehicles, electric vehicles, fuel cell vehicles) will diffuse further.

■ Buildings

Efficient electric appliances (refrigerators, TVs, etc.), highly efficient water-heating systems (heat pumps, etc.), efficient air conditioning systems and efficient lighting will diffuse further, with heat insulation enhanced.

Supply side technologies

■ Renewable energies

Wind power generation, solar photovoltaic power generation, concentrated solar power (CSP) generation, biomass-fired power generation and biofuels will penetrate further.

■ Nuclear

Nuclear power plant construction will be accelerated with capacity factor improved.

■ Highly efficient fossil fuel-fired power generation technologies

Coal-fired power plants (SC, USC, A-USC, IGCC) and natural gas–fired more advanced combined cycle (MACC) plants will penetrate further.

■ Technologies for next-generation transmission and distribution networks

Lower loss type of transformation and voltage regulator will penetrate further.

■ Carbon capture and storage

Note: SC stands for super critical power generation, USC for ultra super critical power generation, and A-USC for advanced ultra super critical power generation.

1.2 Major assumptions

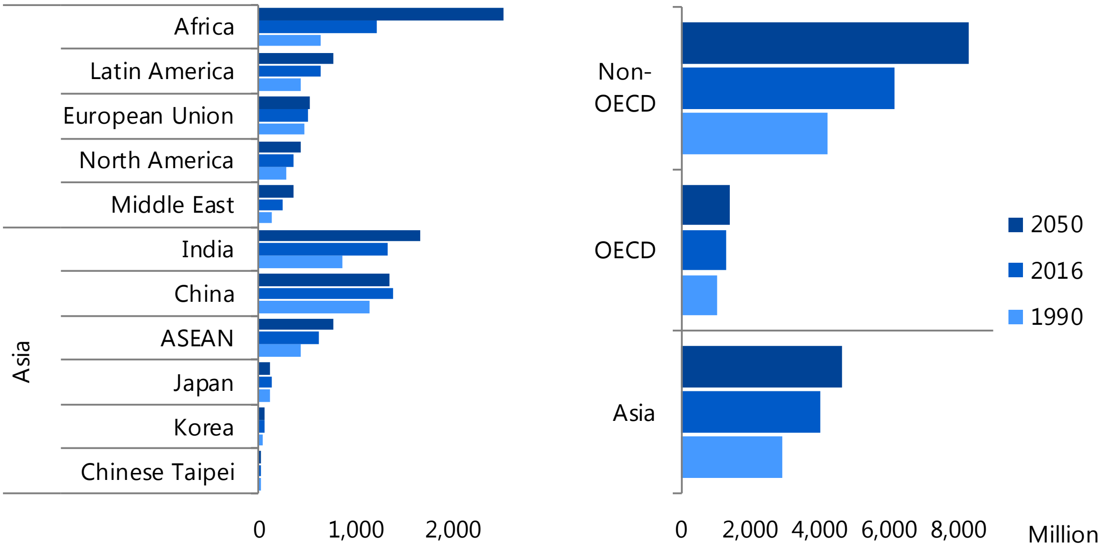
The energy supply and demand structure is subject to population, economic growth and other social and economic factors, including energy prices, energy utilisation technologies, and energy and environment policies. The following assumptions for population and economic growth among these factors are common to the two scenarios.

Population

In assuming population changes, we referred to the United Nations' "World Population Prospects." The total fertility rate (TFR) in many OECD countries, or the average number of children that would be born to a woman during her lifetime, has slipped below 2. Such a low TFR increases the downward pressure on population. The TFR in non-OECD countries is also trending down, in line with income growth and women's increasing social participation. However, non-OECD countries population will continue to increase due to a declining mortality rate, the result of better medical technologies and improved food and sanitation conditions. Overall, global population will increase at an annual rate of around 0.8%, expanding to 9.7 billion in 2050 from 5.3 billion in 1990 and 7.4 billion in 2016 (Figure 1-3, Appendix Table 3).

Among OECD countries, North American countries, particularly the United States, will post a relatively steady population increase due to a massive population influx from abroad and a high TFR. However, the increase will be moderate, with the United States' share of global population falling slightly. In Europe, population will decrease in Germany and Italy while increasing moderately in France and the United Kingdom. The total population of the European Union will increase very moderately before turning downward. Among Asian countries, Japan's population has been declining since 2011 and will post the fastest population fall in the world in the future. In 2016, its elderly population was more than twice its young population, indicating a further fall in the birth rate and further population aging in the future. In Korea, population will peak out in the middle of the 2030s.

Figure 1-3 | Population



Non-OECD population will continue increasing substantially, driven by Africa and populous countries. African population will increase at a high annual rate of 2.2% as a drop in the mortality rate counters a gradual fall in the birth rate. Middle Eastern population will expand about 1.5-fold due to governments' financial incentives for increasing population and a growing population influx from other regions. In non-OECD Europe, Russia has been plagued with a population decline since the collapse of the Soviet Union and will see a continued downward trend. East European countries will expand population moderately. In Asia, India will maintain a high population growth rate, with its population surpassing the Chinese population in the first half of the 2020s. By 2050, India will have the world's largest population at about 1.7 billion. China's population, currently the largest in the world, will peak at 1.415 billion around 2030 and decrease by about 75 million toward 2050. China is the only country with more than 100 million elderly people aged 65 or more and will see further population aging. As the young population concentrates in urban regions, the issue of rural population aging will grow more serious. Population in the Association of Southeast Asian Nations (ASEAN) will increase to 760 million in the 2050s, surpassing half the Chinese population size.

Asia will experience a continuous population increase, but its share of global population will fall slowly from 54% in 2016 to 48% in 2050.

Economy

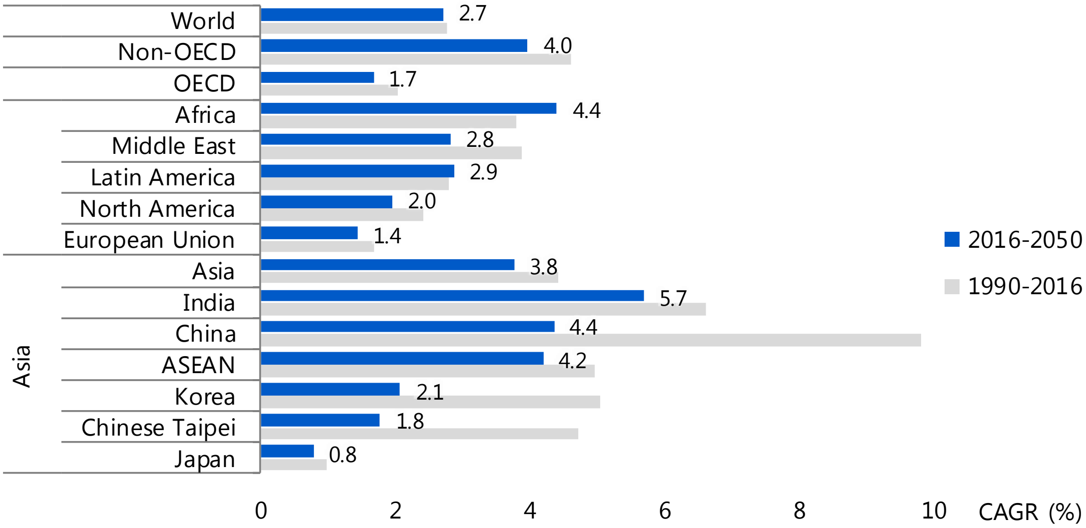
The world economy is currently comprised of various country-by-country economic growth rates accompanying oil price hikes, escalating trade disputes or domestic political uncertainties. The United States, the largest economy in the world, is growing remarkably among OECD countries thanks to employment and income environment improvements and personal income tax cuts under a tax reform, while concerns about trade and other policies of the Trump administration may hindered future growth. The European economy, second to the U.S. economy, is continuing its growth led by East European countries, despite uncertainties about its trade dispute with the United States and other matters. The Chinese economy, the third largest after the United States and Europe, has begun to accelerate economic growth on tax cuts. However, its future course is uncertain due to its retaliation against U.S. tariff hikes. While oil prices have been rising, the prolonged joint production cut by oil producing countries has exerted downward pressure on resource-rich countries including Russia as well as Middle Eastern and Latin American countries. Some emerging economies such as Turkey are contracting due to changes in U.S. trade policy.

Over a medium to long term, many economies are likely to expand through population growth, productivity growth, technological innovation, appropriate fiscal and monetary policies and international collaboration. Among them, India will increase its presence as a new driver of the global economic growth in the future. Although structural reform and other policies are currently exerting negative effects and taking time to penetrate the economy, these policies will promote domestic demand expansion and foreign investment over a long term. These policies should also allow the Indian economy to grow at the world’s fastest annual pace of 5.7% over the outlook period. The ASEAN economy will grow at an annual rate of 4.2%.

In this way, Asia is expected to remain the centre of global economic growth. However, Asia has yet to achieve its long-term challenge of making a transition to a domestic demand-led economy. Rising wages and citizens’ growing consciousness of rights will force Asia to switch from export-oriented economic growth that takes advantage of abundant surplus labour and low wages.

In consideration of the above-explained situation combined with the economic outlooks of the International Monetary Fund, the Asian Development Bank, other international organisations as well as individual government’s economic development programs, we assumed the world’s annual economic growth rate at 2.7% over the outlook period (Figure 1-4, Appendix Table 4).

Figure 1-4 | Real GDP growth



International energy prices

An oil price crash came in the second half of 2014 because of many different factors. A deceleration of the economic growth in Europe and China, a crude oil production expansion in the United States and a decision against oil production cuts by the Organization of the Petroleum Exporting Countries (OPEC) causing a glut in the international oil market. The Brent crude oil futures price sank as low as $30.80 per barrel in January 2016. Despite further U.S. crude oil production expansion, oil prices later rose back on OPEC's agreement for a coordinated oil production cut, with the Brent price average standing at around $70/bbl in September 2018. However, how long OPEC will continue the coordinated production cut is uncertain.

In the Reference Scenario, oil demand will keep on increasing in line with firm global economic growth. While U.S. and other non-OPEC oil production will continue an upward trend on the supply side, oil importing countries will still be heavily dependent on OPEC and Russia both plagued with geopolitical risks. At the same time, marginal oil production costs will rise on a shift to small and medium-sized, polar and ultra-deep-sea oil fields where production costs are relatively higher. No tough restrictions on excessive money inflow into the futures market are likely to be introduced, indicating that speculative investment money could push up oil prices. Given these factors, oil prices are expected to fluctuate wildly over the short term and gradually rise over the medium to long term. The real oil price (in 2016 dollars) is assumed to increase to $95/bbl in 2030 and $125/bbl in 2050 (Table 1-1). Under an assumed annual inflation rate of 2%, the nominal price is projected to reach $123/bbl in 2030 and $240/bbl in 2050.

Natural gas prices will remain low in the United States. In line with development and production cost hikes, however, they will rise from current record-low levels. Japan's real natural gas import price is assumed to rise from $8.1 per million British thermal units in 2017 to $10.8/MBtu in 2050 in the Reference Scenario. Liquefied natural gas exports from the United States have started and are expected to contribute to diversifying LNG supply sources for

Japan and eliminate or ease the problem of the so-called destination clause for LNG imports, leading the LNG price for Japan to gradually deviate from oil prices. Currently, the price-cutting effect of U.S. LNG exports is limited. The price in Japan will still be higher than in Western countries due to limitations on reducing liquefaction and maritime transportation costs.

Coal prices have fallen considerably low, reflecting the loose supply-demand balance. Despite less resource constraints for coal, however, coal prices will rise due to growing Asian demand for coal for power generation and a rebound from the earlier low levels. Nevertheless, prices per thermal unit for coal will still be lower than those for oil or natural gas.

Table 1-1 | International energy prices

Real prices			Reference			Advanced Technologies		
		2017	2030	2040	2050	2030	2040	2050
Crude oil	$2017/bbl	54	95	115	125	80	80	80
Natural gas								
Japan	$2017/MBtu	8.1	10.5	10.7	10.8	9.9	9.9	9.9
Europe (UK)	$2017/MBtu	5.8	8.2	8.8	8.9	7.8	7.8	7.9
United States	$2017/MBtu	3.0	4.2	5.0	5.2	3.8	3.9	4.0
Steam coal	$2017/t	99	96	107	111	85	85	85

Nominal prices			Reference			Advanced Technologies		
		2017	2030	2040	2050	2030	2040	2050
Crude oil	$/bbl	54	123	181	240	103	126	154
Natural gas								
Japan	$/MBtu	8.1	13.5	16.9	20.8	12.8	15.6	19.0
Europe (UK)	$/MBtu	5.8	10.6	13.9	17.1	10.1	12.3	15.2
United States	$/MBtu	3.0	5.4	7.9	10.0	4.9	6.1	7.7
Steam coal	$/t	99	124	169	213	110	134	163

Note: The annual inflation rate is assumed at 2%.

In the Advanced Technologies Scenario, fossil fuel demand will decline on energy conservation and transition to nuclear and renewable energy. As a result, oil and natural gas prices will be lower than in the Reference Scenario. Coal prices will fall from current levels as demand for coal for power generation decreases sharply in Asia.

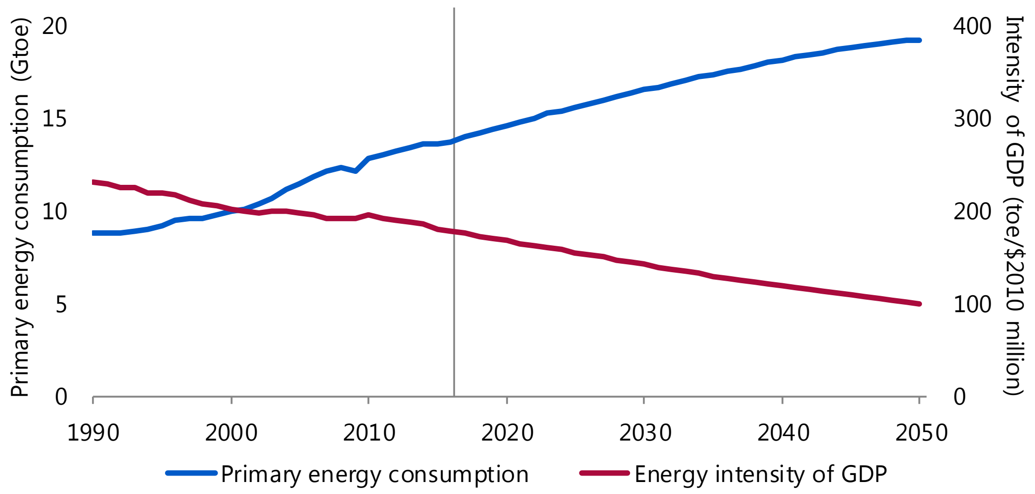
2. Energy demand

2.1 Primary energy consumption

World

In recent years, the growth in global primary energy consumption has decelerated despite robust economic growth. From 1.4% per annum for four consecutive years from 2011, when the direct impact of the global financial crisis began to ease, the average annual growth in global primary energy consumption declined to 0.5% for 2015 and 2016. The energy-GDP elasticity[8], an indicator of energy consumption's relationship with economic growth, decreased substantially from 0.52 to 0.20. Some analysts interpret this change as indicating an ongoing decoupling between energy and economy. In fact, OECD energy consumption peaked in 2007, attesting to the decoupling, while non-OECD energy consumption has increased robustly. The recent deceleration may be a temporary phenomenon accompanying China's production adjustment for steel, cement and other products amid its economic growth slowdown. According to China Energy Development 2017, China's gross energy consumption in 2017 scored an annual increase of 2.9%, up 1.5 percentage points from 2016.

Figure 2-1 | Global primary energy consumption and energy intensity [Reference Scenario]



In addition to China, there are many regions with high growth potential, including India, ASEAN and Africa. These generally poor regions have yet to enjoy sufficient energy supply. Their energy demand will increase more and more in line with their economic development and living standard improvement (indicating energy is required for economic development).

In the Reference Scenario where current social, economic, policy and technology introduction trends involving energy supply and demand are assumed to continue, global primary energy consumption will increase 1.4-fold from 13,761 million tonnes of oil equivalent (Mtoe) in 2016

8 Energy-GDP elasticity = Primary energy consumption change / real GDP change.

to 19,275 Mtoe in 2050 (Figure 2-1). While annual GDP growth will stand at 2.7%, annual energy consumption will be limited to 1.0% due to progress in energy conservation (the energy-GDP elasticity is projected at 0.37). However, this indicates that limiting rise in energy consumption while promoting economic growth would be difficult (particularly in non-OECD countries) with energy policies and conservation technologies assumed in the Reference Scenario alone.

Figure 2-2 | Primary energy consumption in selected countries / regions [Reference Scenario]

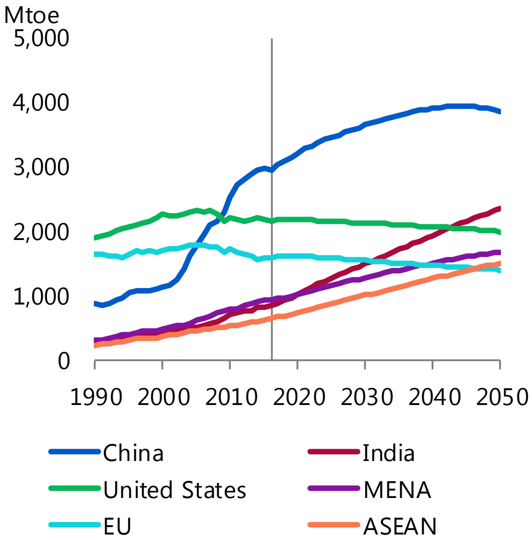
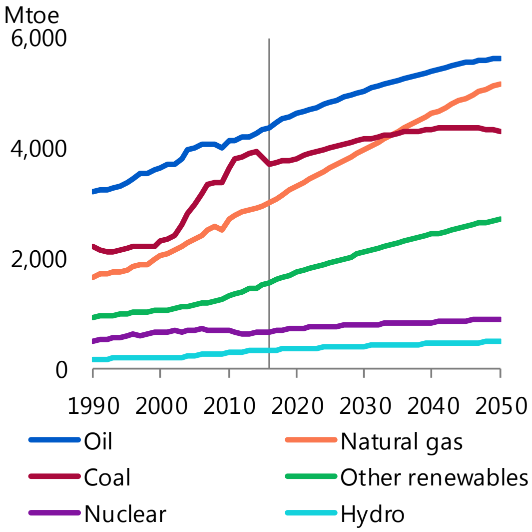
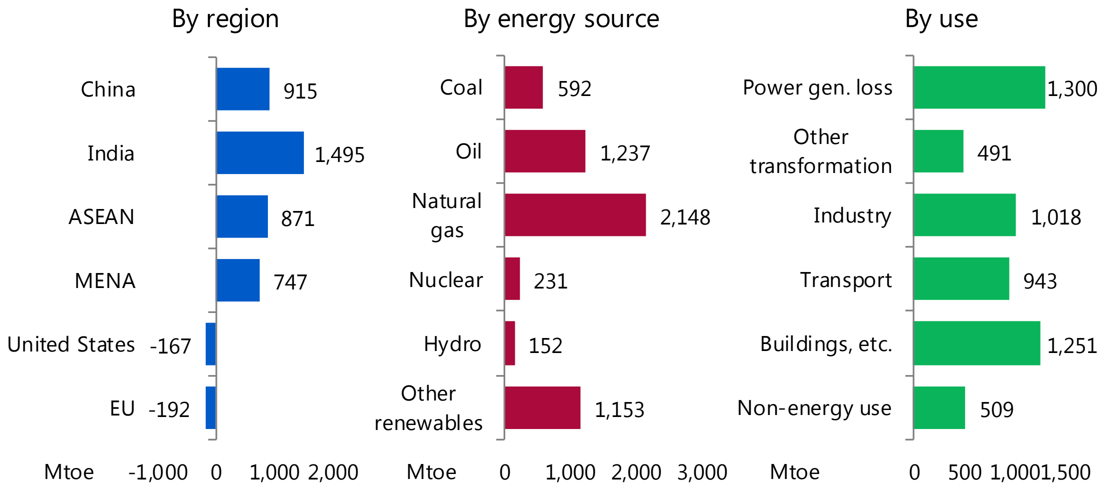


Figure 2-3 | Global primary energy consumption [Reference Scenario]



Asia with its huge population and high growth potential will continue to make great contributions to the global energy consumption growth (Figures 2-2 and 2-4). Asia's share of global energy consumption will rise from 40% in 2016 to 47% in 2050. After driving global energy consumption growth so far, however, China will decelerate its consumption growth due to population aging and decline and its energy consumption will peak out in the middle of the 2040s. In its place, India and ASEAN, with relatively younger populations, are expected to continue to experience high economic growth and will expand energy consumption substantially. Their share of global energy consumption will increase from a combined 11% at present to 20% in 2050, rivalling China. Following them, the Middle East and North Africa (MENA) which also feature younger populations, will raise their consumption sharply. Meanwhile, developed countries including the United States and the European Union will keep on reducing energy consumption.

Figure 2-4 | Primary energy consumption growth [Reference Scenario, 2016-2050]



Among energy sources, natural gas will feature the largest consumption growth, accounting for about 40% of the overall growth (Figures 2-3 and 2-4). Natural gas will post an annual consumption increase of 1.6% due to growth in the power generation sector and will replace coal as the second most consumed energy source after oil in the second half of the 2030s. Oil will log the second largest annual consumption growth of 0.7% primarily to supply the transport sector (including automobiles and international bunkers). Oil will remain the most consumed energy source, though with its share of primary energy consumption declining. Coal will score an annual consumption growth of only 0.4%, slower than the growth for oil or natural gas, because of increasing air pollution and climate change policies aimed at holding down coal consumption in the power generation sector. Non-fossil energy sources including nuclear and renewables will register an annual consumption increase of 1.4%. Solar and wind power[9] will increase at a high annual rate of 5.0%, though with their share of primary energy consumption being limited to 4% in 2050. Fossil fuels (oil, coal and natural gas) will still maintain a high share of the primary energy consumption at 79% even in 2050, against 81% at present. In recent years, many countries or regions have been seeking to reduce their dependence on fossil fuels to help mitigate climate change, however, even the European Union with its ambitious climate change countermeasures will still depend on fossil fuels for more than 60% of primary energy consumption in 2050 (Figure 2-5). Meanwhile, India and ASEAN with remarkable economic growth will increase their dependence on fossil fuels more and more.

[9] Including solar thermal and marine power generation.

Figure 2-5 | Dependence on fossil fuels in selected countries and regions [Reference Scenario]

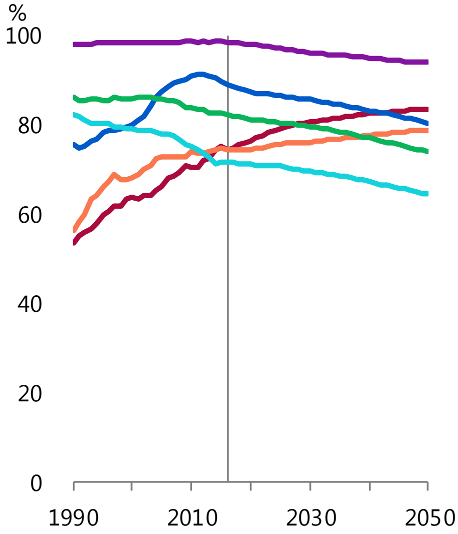
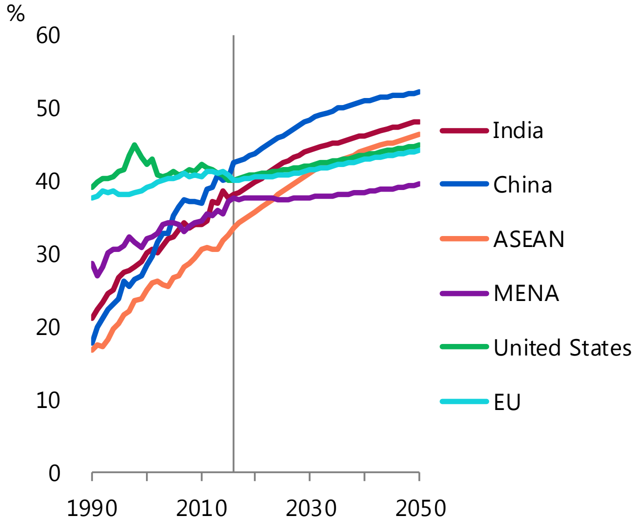


Figure 2-6 | Electrification rates (on the supply side) [Reference Scenario]



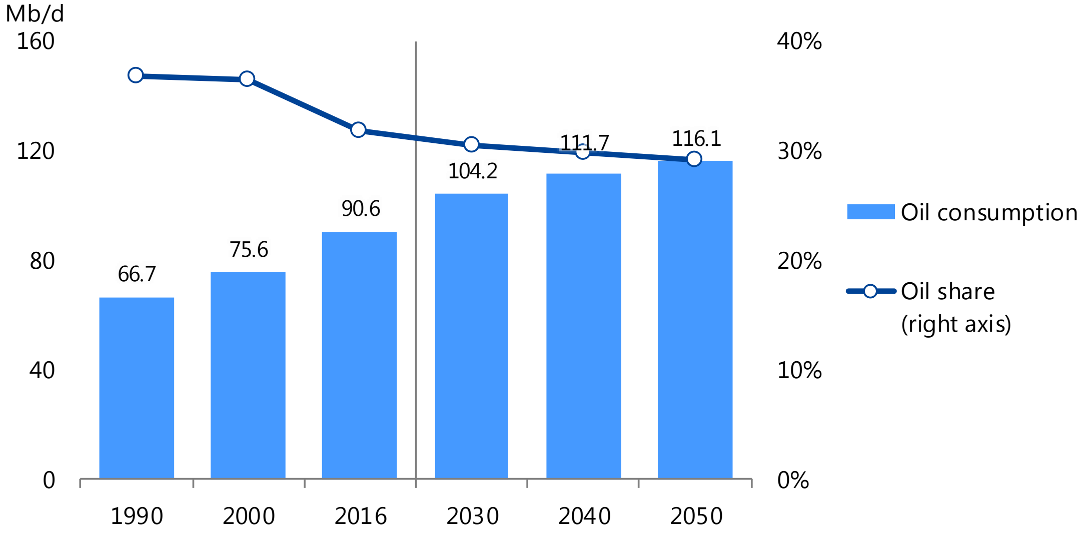
By sector, power generation will post the largest growth in energy consumption (Figure 2-4). Supported by income hikes and infrastructure development in unelectrified regions, electricity will be used more and more for its convenience. Therefore, energy consumption for power generation will increase. The electrification rate on the supply side[10] will post rapid growth particularly in Asia (Figure 2-6). The improvement of power generation efficiency and the reduction of power transmission and distribution losses will be required to limit the rise in the electrification rate on the supply side.

Oil

Oil consumption for transportation and petrochemical production will robustly increase through 2050. From 90.6 million barrels per day (Mb/d) in 2016, oil consumption will expand at an annual rate of about 0.7% to more than 100 Mb/d in the middle of the 2020s and 116.1 Mb/d in 2050 (Figure 2-7). The consumption increase at 25.5 Mb/d will surpass the combined production (about 25 Mb/d) in the United States and Saudi Arabia, the world's first and second largest oil producers at present. Oil will remain the most consumed energy source, though with its share of primary energy consumption falling from 32% in 2016 to 29% in 2050.

[10] The percentage share of energy consumption for power generation in total primary energy consumption.

Figure 2-7 | Global oil consumption and its share of primary energy consumption [Reference Scenario]



OECD oil consumption peaked and started a downtrend in the mid-2000s and will continue to decrease at an annual rate of 0.8% (Figure 2-8). About 80% of the decline of 9.3 Mb/d from the present level to 2050 will be accounted for by a fall in automobile fuel consumption, indicating the great effect of fuel efficiency improvement, including electrification. Meanwhile, non-OECD oil consumption will increase at a firm annual rate of 1.6%. Of the increase of 30.8 Mb/d through 2050, automobiles will account for 44%, non-energy use for 17% and the buildings sector and others for 16%. Non-OECD's share of global oil consumption will expand from 48% in 2016 to 64% in 2050. Asia will command some 40%.

China will replace the United States as the world's largest oil consumer around 2030. However, its oil consumption will peak out in the mid-2040s and the downturn will be attributable primarily to a decline in automobile fuel consumption. While fuel efficiency will be improved, vehicle ownership growth will also peak on a population fall. Oil consumption will rise 2.9-fold in India from 2016 to 2050 and 2.1-fold in ASEAN. China, India and ASEAN will expand oil imports to meet domestic consumption growth causing a fall of the oil self-sufficiency rate from 37% to 23% in China, from 19% to 4% in India and from 55% to 21% in ASEAN. As Asia includes many resource-poor countries and has no choice but to rely heavily on oil imports, energy security will become an important challenge for Asia.

Figure 2-8 | Oil consumption in selected countries / regions [Reference Scenario]

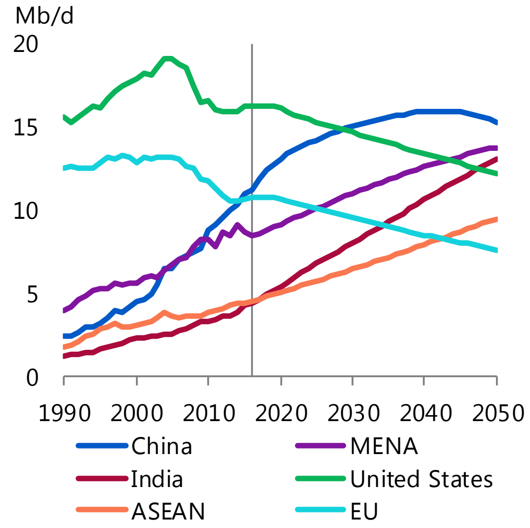
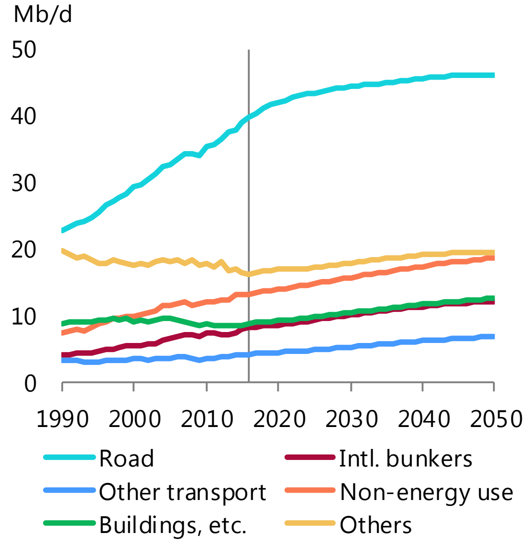


Figure 2-9 | Global oil consumption [Reference Scenario]



More than half of the consumption growth through 2050 will be accounted for by the transport sector, including vehicle fuel consumption (Figure 2-9). Global vehicle ownership[11] will double, with growth centring on non-OECD. Despite fuel efficiency improvement, vehicle fuel consumption will increase by 6.5 Mb/d. Oil consumption by international bunkers (aviation and marine) will increase at an annual rate of 1.2% due to the expansion of international travel and trade, capturing 10% of total oil consumption. The non-energy use sector including petrochemical feedstocks and lubricant will expand consumption by 5.4 Mb/d. Given high demand for plastics and other petrochemical products, the petrochemical industry is expected to benefit from a robust growth. In the buildings sector, oil consumption for water heating and cooking will increase substantially mainly in non-OECD. In line with income improvement, mainly rural areas will switch to oil from coal and solid biomass fuel that are detrimental to health. In 2050, the transport sector will account for 56% of oil consumption (40% for automobiles and 10% for international bunkers), the non-energy use sector will account for 16% and the buildings sector and others for 11%.

Oil is positioned as a strategic good because of its importance. How to secure stable oil supply at appropriate prices is a key energy security challenge, particularly for oil importing countries. Therefore, rising dependence on oil imports accompanying vehicle fuel consumption growth is a painstaking problem. Automobiles are diffusing rapidly in China, India, Southeast Asia and other regions and air pollution has become a serious issue. Given climate change countermeasures, the reduction of vehicles' oil consumption is an urgent challenge. One of the

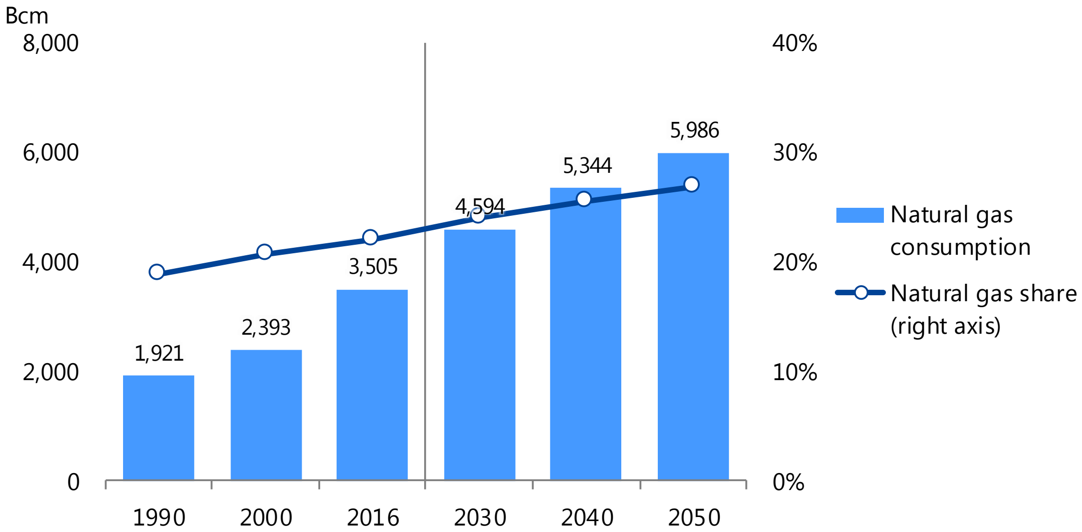
[11] The downward pressure of progress in car sharing services on vehicle ownership growth is not considered here. Unless transport demand changes, the pressure will be neutral to vehicle fuel consumption due to a rise in the operating rate of car sharing services. However, the effect of car sharing on transport demand and the impact of growth in automatic driving are uncertain and should be studied in the future.

key measures to reduce such oil consumption is the diffusion of electric vehicles accompanied by the low-carbonisation of the power generation sector. France and the United Kingdom have come up with plans to ban sales of gasoline and diesel vehicles from 2040. Some other countries including China and India are considering similar regulations. If these policies gain momentum, oil consumption growth may decelerate or become negative (see IEEJ Outlook 2018 for the impact of such development).

Natural gas

Natural gas will record the largest consumption growth among all energy sources due to the power generation sector's switching steadily from coal to natural gas and a final natural gas consumption increase. Natural gas consumption will expand 1.7-fold from 3,505 billion cubic metres (Bcm) in 2016 to 5,986 Bcm in 2050 (Figure 2-10). Natural gas will increase its share of primary energy consumption from 22% in 2016 to 27% in 2050, becoming the second largest energy source after oil.

Figure 2-10 | Global natural gas consumption and natural gas's share of primary energy consumption [Reference Scenario]



Non-OECD will account for 87% of the natural gas consumption growth of about 2,481 Bcm from 2016 to 2050 (Figure 2-11). Through growth, the non-OECD share of global natural gas consumption will expand from 53% to 67%. Among non-OECD countries, China, India, and MENA will post remarkable growth. Natural gas demand will expand by 442 Bcm in China and by 357 Bcm in India in the next 34 years. The Middle East has limited domestic oil consumption and promoted domestic natural gas utilisation to earn foreign currencies with oil exports and expanded petrochemical plants using natural gas to generate jobs. MENA natural gas consumption will top U.S. consumption in the mid-2030s. Japan's natural gas consumption will decline by 22 Bcm from the present level by 2050 and the European Union's consumption will turn downward in the mid-2030s. U.S. consumption will increase by 108 Bcm by 2050, a remarkable rise among OECD countries. In the United States, natural gas will surpass oil in consumption, becoming the largest energy source.

Natural gas consumption for power generation among gas uses will increase substantially due to technological progress, economic efficiency and environmental considerations. As a result, the power generation sector will account for half of the natural gas consumption growth (Figure 2-12). Natural gas will be growingly used for power generation as oil-fired power generation costs more and coal faces environmental issues. Natural gas will expand its share of global power generation to 29% in 2050, narrowing its share gap with coal to 1 percentage point. After the power generation sector, the industry sector will post the second fastest growth in natural gas consumption. In view of convenience and environmental considerations, the sector will growingly switch from oil and coal to natural gas. China will account for about three quarters of the natural gas consumption growth in the buildings sector and others as China is rapidly switching to city gas from solid fuels such as coal and fuel wood that cause indoor and outdoor air pollution.

Figure 2-11 | Natural gas consumption in selected countries / regions [Reference Scenario]

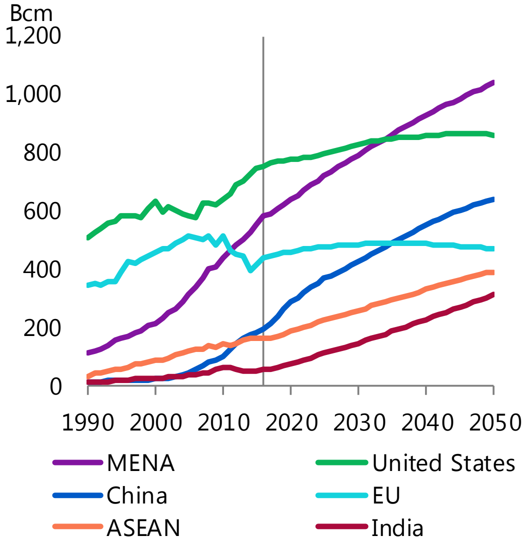
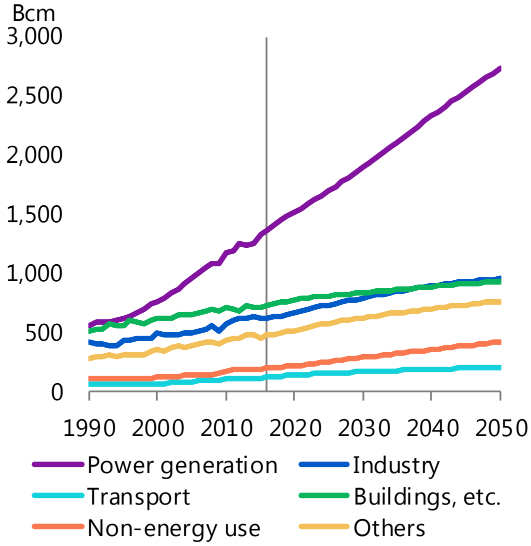


Figure 2-12 | Global natural gas consumption [Reference Scenario]

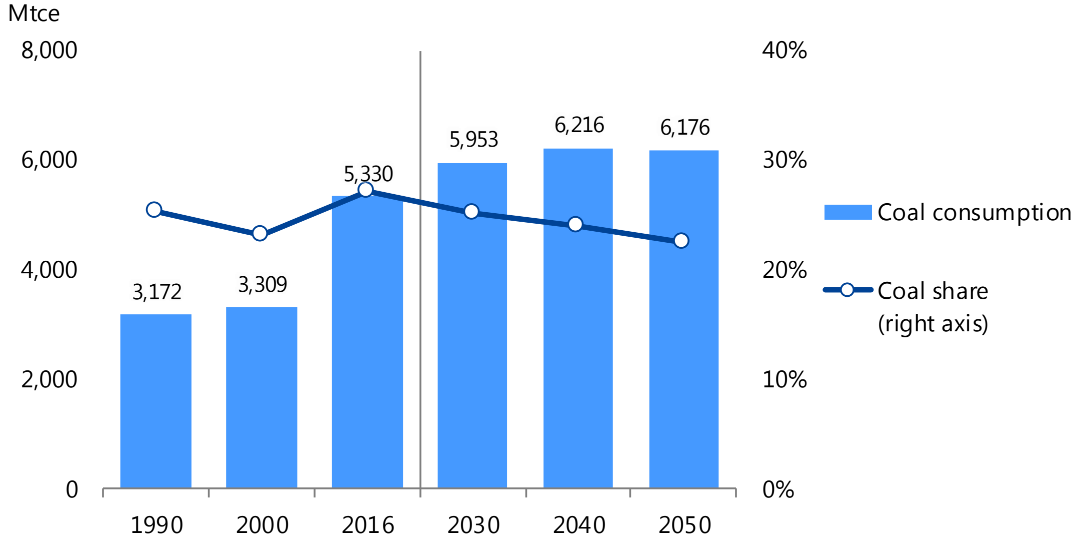


Coal

Coal's consumption trend will be different from those for oil and natural gas. As air pollution, climate change and other coal-related problems encourage mainly developed countries to switch from coal to other energy sources, coal consumption will post more moderate growth than oil and natural gas before peaking in the second half of the 2040s (Figure 2-13). Global coal consumption will increase by 16% from 5,330 million tonnes of coal equivalent (Mtce[12]) at present to 6,176 Mtce in 2050. Most of the increase will be for power generation. Coal's share of primary energy consumption will narrow from 27% in 2016 to 22% in 2050.

[12] 1 tce = 0.7 toe

Figure 2-13 | Global coal consumption and its share of primary energy consumption [Reference Scenario]



In China that accounts for 51% of the global coal consumption, industrial coal consumption will plunge by about 40% by 2050 as steel and cement production is peaking. Due to increasing consumption for power generation, however, China's coal consumption will moderately increase until the mid-2030s before turning downward thereafter. Chinese coal consumption will remain the largest in the world (accounting for 42% of global consumption in 2050). In OECD countries including the United States and European Union members, increasing taxes on coal-fired power plants, enhanced regulations on CO_2 and mercury emissions, competition from natural gas and other factors will force coal-fired power generation to decline. While OECD primary coal consumption will decline by 529 Mtce or 42% by 2050, non-OECD consumption will increase by 1,375 Mtce or 34%. Asia will account for 91% of the non-OECD growth. While China's coal consumption growth will be limited, India and ASEAN will drive the Asian consumption growth. India, which already overtook the United States in coal consumption, will post a greater increase than any other country (Figure 2-14).

As coal resources can be found in many areas in the world, coal can be supplied in a far more stable manner than oil or natural gas which are found only within a limited range of regions. Due to lower prices, coal consumption will increase mainly in the power generation sector (Figure 2-15). Coal consumption in that sector will increase at an annual rate of 0.7% through 2050, posting a total rise of 1.3-fold from the present level. As a matter of course, all the rise will be seen in non-OECD. In a bid to address climate change, however, financial and investment industries in the world are considering the prohibition of loans for coal-fired power generation projects. In non-OECD countries that have less capacity to raise funds on their own, coal-fired power plant investment assumed in the Reference Scenario could be overestimated (see Chapter 7 Impact of banning construction of new coal-fired power plants).

Figure 2-14 | Coal consumption in selected countries / regions [Reference Scenario]

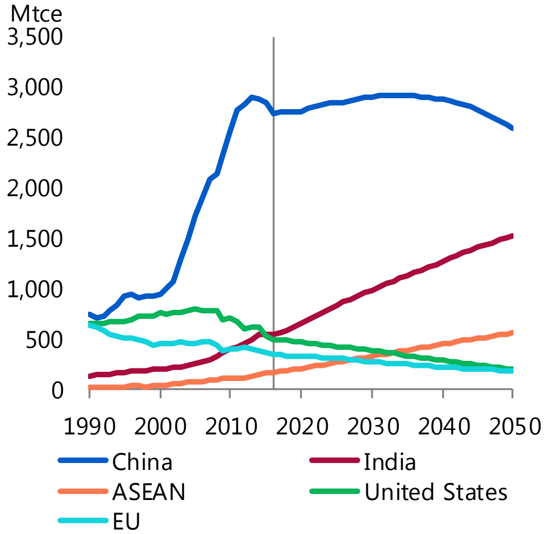
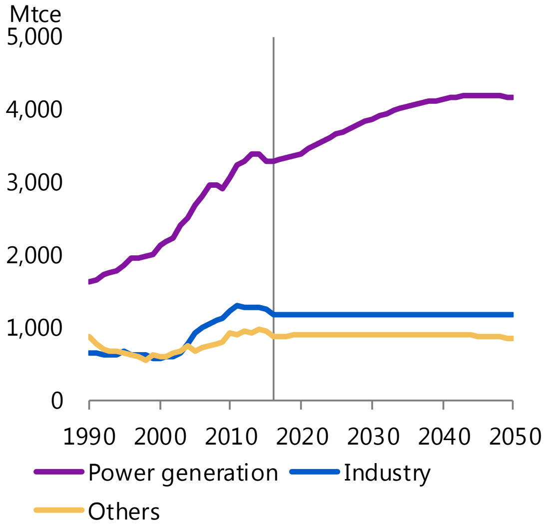


Figure 2-15 | Global coal consumption by sector [Reference Scenario]



Non-fossil energy

Although non-fossil energy consumption will expand 1.6-fold by 2050, its share of primary energy consumption will rise only slightly from 19% in 2016 to 21% in 2050. Power generation accounts for 53% of non-fossil energy consumption at present. Nuclear and hydro capture a large share of the non-fossil energy consumption for power generation (Figure 2-16). Meanwhile, non-fossil energy consumption mostly for heat utilisation represents solid biomass including firewood and livestock manure used in rural areas of developing countries (Figure 2-17).

More than 90% of future non-fossil energy consumption will be for power generation and solar, wind and other non-hydro renewables[13] will post the largest consumption growth among non-fossil energy sources. Their consumption will increase more than six-fold from 114 Mtoe in 2016 to 705 Mtoe in 2050. Nuclear consumption will log the second largest consumption growth after these renewables' rise, increasing from 680 Mtoe in 2016 to 911 Mtoe in 2050. However, their shares of primary energy consumption will remain small. The share in 2050 will stand at 4.0% for solar, wind and other non-hydro renewables and 4.7% for nuclear.

Meanwhile, heat utilisation through non-fossil energy consumption will grow little. This is because rural areas accounting for most of such non-fossil energy consumption for heat utilisation will switch from traditional biomass to electricity and gas, in line with living standard improvement. Heat utilisation through solid biomass consumption will lower its share of direct heat demand in final energy consumption from 12% at present to 10% in 2050. Liquid biomass fuels and biogas consumption mainly for automobiles and buildings will

[13] Solar, wind and other non-hydro renewables cover solar photovoltaics, wind power generation, solar thermal power generation and marine power generation.

double through 2050. However, the absolute volume of such consumption will be limited to only 1.8% of direct heat demand.

Figure 2-16 | Non-fossil energy consumption for power generation [Reference Scenario]

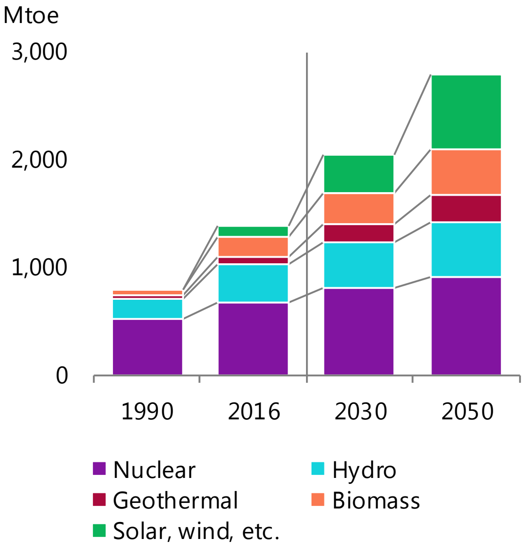
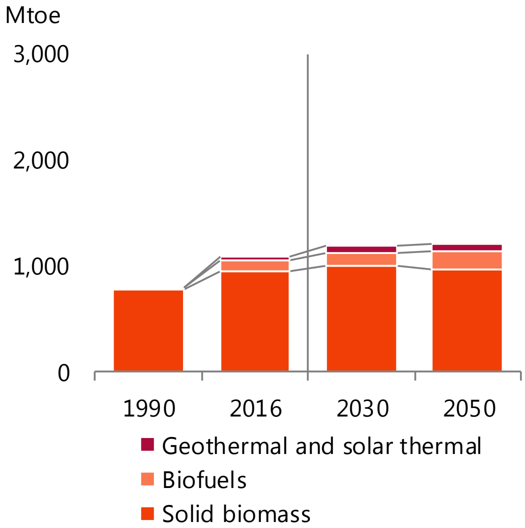


Figure 2-17 | Non-fossil fuel consumption for heat utilisation [Reference Scenario]



Asia

Asian primary energy consumption will grow at an annual rate of 1.5% from 5,497 Mtoe in 2016 to 8,987 Mtoe in 2050 in line with its robust economic growth (Figure 2-18). The increase of 3,490 Mtoe will account for more than 60% of the global energy consumption growth and its share will increase from 40% in 2016 to 47% in 2050.

China's energy consumption that currently accounts for 54% of Asian consumption will decelerate its rate of growth until it turns negative in the mid-2040s, due to population aging and decline. In its place, India and ASEAN, which are expected to continue robust economic growth on the strength of relatively younger populations, will expand energy consumption substantially. India will account for 43% of Asian consumption growth and ASEAN for 25%. Among ASEAN members, Indonesia and Viet Nam will post rapid growth, accounting for a combined 63% of ASEAN energy consumption growth (Figure 2-19). Meanwhile, energy consumption in more mature economies such as Japan, Korea and Chinese Taipei will decrease or remain almost unchanged. The centre of gravity for the Asian energy market will shift in a clockwise fashion from East Asia to Southeast and South Asia.

At present, coal accounts for 49% of Asian primary energy consumption, followed by 25% for oil and 10% for natural gas. Asia thus depends on fossil fuels for a combined 84% of its primary energy consumption. Its dependence on fossil fuels will slightly decline but will still be as high as 81% in 2050. Among fossil fuels, coal will reduce its share by 9 percentage points, while natural gas will expand its share by 7 points. This is mainly because the power generation sector will favour natural gas which is more environmentally friendly. With regard to non-fossil fuel consumption, nuclear will increase 3.3-fold from a small level and non-biomass renewables 3.0-fold. On the other hand, traditional biomass consumption including fuelwood and livestock manure will decrease by 30%.

Figure 2-18 | Asian primary energy consumption [Reference Scenario]

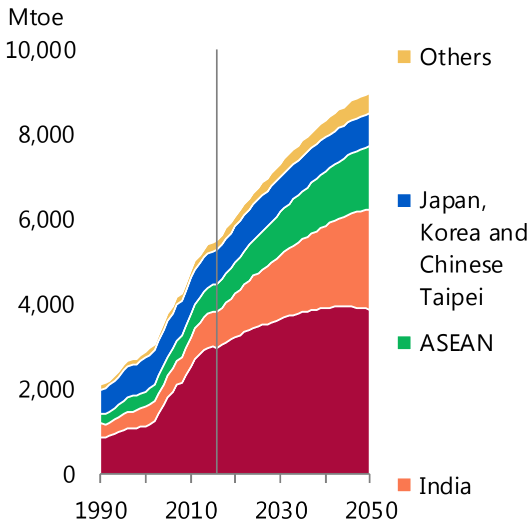


Figure 2-19 | ASEAN primary energy consumption [Reference Scenario]

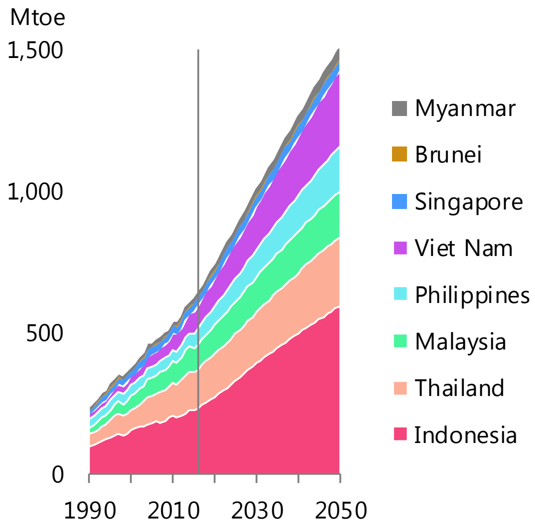
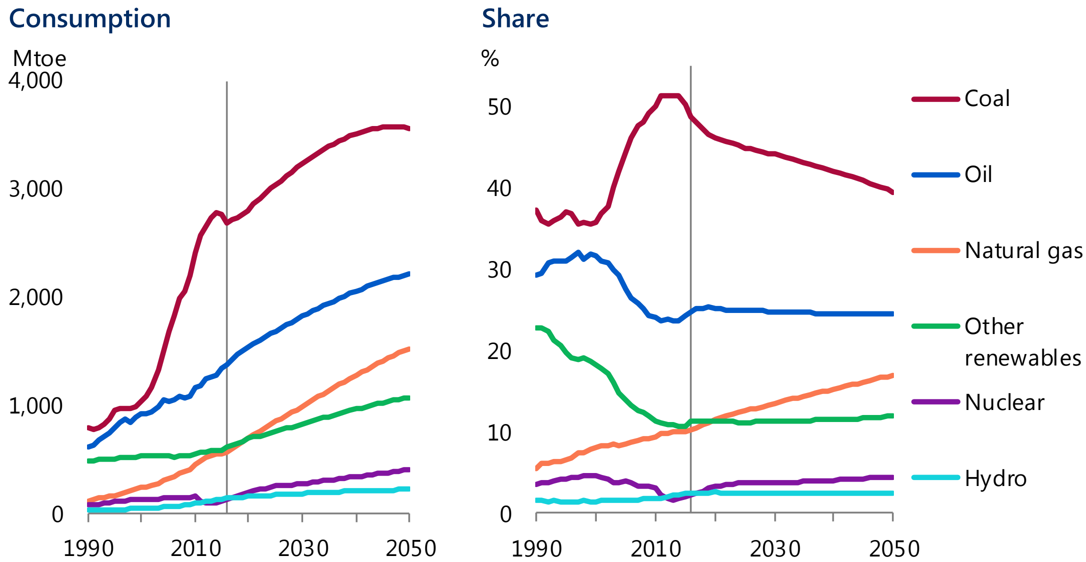


Figure 2-20 | Asian primary energy consumption [Reference Scenario]



Asian oil consumption will expand from 28.2 Mb/d in 2016 to 45.5 Mb/d in 2050 (Figure 2-21). The average annual growth will be 1.4%, twice as high as the global growth at 0.7%. Oil consumption will increase in the transport sector (up 9.7 Mb/d), the buildings sector (up 3.2 Mb/d) and the non-energy use sector (up 3.1 Mb/d). Those three sectors will account for

92% of total oil consumption growth in Asia. India will capture 50% or the largest share of the Asian oil consumption growth, followed by 29% for ASEAN and 24% for China. Oil consumption will decrease in Japan, Korea and Chinese Taipei. Asia will command two-thirds of global oil consumption growth, raising its share of global oil consumption from 31% to 39%. As Asia expands oil imports to meet such consumption growth, its oil self-sufficiency rate will fall from 28% at present to 14% in 2050 (Box 2-1). Asia's presence in the international market is increasing as about 80% of the oil for international transactions will be consumed in Asia.

Asian natural gas consumption will increase 2.7-fold from 654 Bcm in 2016 to 1,761 Bcm in 2050, with an annual growth averaging 3.1%, more than twice faster than the oil consumption growth (Figure 2-22). The power generation sector accounts for 45% of the natural gas consumption and will capture more than half of the future consumption growth. Asia's share of global natural gas consumption will expand from 19% in 2016 to 29% in 2050. Particularly, China will make great contributions to the Asian natural gas consumption growth, boosting its consumption more than three-fold from the present level to 639 Bcm in 2050, accounting for 11% of global consumption. Indian natural gas consumption, though declining from 2011 before turning upward in 2016, will increase mainly for power generation in the future. Japan, now a major LNG importer, will reduce its natural gas consumption due to progress in energy conservation and the expansion of non-fossil energy consumption.

Figure 2-21 | Asian oil consumption [Reference Scenario]

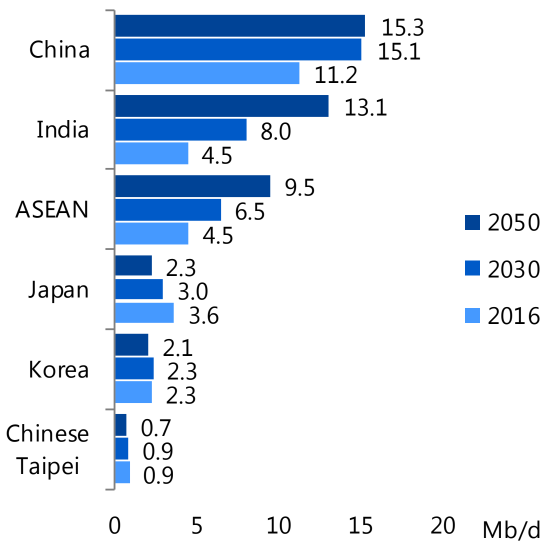
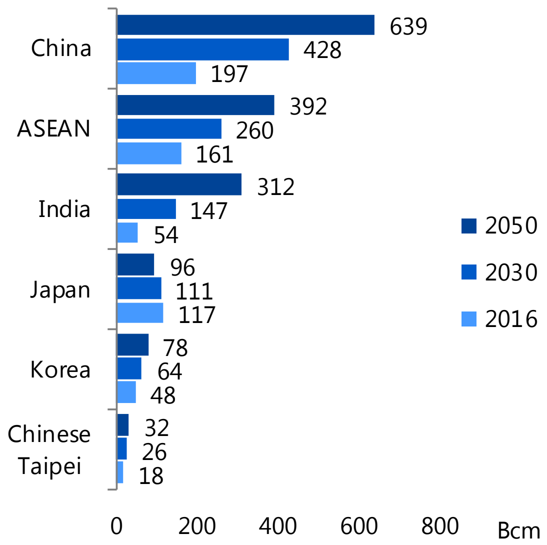


Figure 2-22 | Asian natural gas consumption [Reference Scenario]



In line with Asian natural gas demand growth, sales promotion in the Asian natural gas market will grow more active. Russia and many other countries endowed with natural gas resources are paying attention to Asia as a rising market. To achieve stable natural gas supply at low cost, Asian countries should negotiate with resource-rich countries and promote market design and other initiatives. They should also enhance measures against supply disruptions, including natural gas stockpiling and the installation of pipelines for inter-region distribution or supply.

Coal consumption in Asia will rise from 3,835 Mtce in 2016 to 5,082 Mtce in 2050. The growth rate will be the lowest among energy sources and therefore coal's share of primary energy consumption will shrink from 49% in 2016 to 40% in 2050. Coal will remain, however, the largest energy source in Asia. Coal consumption will level off before decreasing slightly in China, accounting for 70% of Asian coal consumption, while continuing robust growth in India and ASEAN with growing economies. While the industry and buildings sectors will reduce coal consumption dramatically, the power generation sector will far more than offset the reduction. Although large-scale fossil fuel-fired power generation will be required to meet robust electricity demand, it will increasingly be more difficult to construct or expand any coal-fired power plants that are lacking considerations for climate change or air pollution. Given that Asia is endowed with coal resources, the region will have to efficiently exploit its coal for economic and energy security reasons.

Asian non-fossil energy consumption will rise from 878 Mtoe in 2016 to 1,698 Mtoe in 2050, expanding its share of total primary energy consumption by 3 percentage points from the present level to 19%. Of the growth, renewables other than biomass will account for 57%, followed by 34% for nuclear. Asia's share of global renewable energy consumption (other than biomass) will expand from 42% in 2016 to 46% in 2050, with China commanding most of the Asian share. The increase in Asian nuclear consumption from 122 Mtoe in 2016 to 404 Mtoe in 2050, will be mainly concentrated on China and India. Nuclear power generation will decline substantially in OECD that now captures 75% of the global nuclear consumption, leading Asia's share of global consumption to soar from 18% at present to 44%.

Box 2-1 | Asian energy self-sufficiency rate

Asia will rapidly expand demand for energy including fossil fuels and will have to depend on imports for most of the demand growth. While Asian oil production will decrease, growing natural gas and coal production in the region will fail to catch up with demand growth. Asia's import expansion will substantially increase its presence in the international energy market as most of the import growth in future global energy trade will emerge from Asia (Figure 2-23). Asia's share of oil trade (imports) will rise from 56% at present to 79% in 2050. This will be the same with natural gas and coal with Asia accounting for about 60% of the natural gas trade and about 70% of the coal trade. While increasing its influence on the international market, Asia will experience a drop in its energy self-sufficiency rate, facing energy security challenges.

In China, the largest energy importer in the world, the energy self-sufficiency rate will fall slightly from 80% at present to 76% in 2050 (Figure 2-24). As the coal self-sufficiency rate remains at around 90% and nuclear and renewable energy consumption increases substantially, the overall energy self-sufficiency rate will not decline so much. India, now the third largest energy importer, will overtake Japan by 2020 and replace China as the largest energy importer in the mid-2040s. India's energy self-sufficiency rate will fall from 65% at present to 56%; the fall is relatively small. However, ASEAN countries' energy self-sufficiency rates will decline more rapidly. Malaysia, now a net energy exporter, will see its energy self-sufficiency rate falling below 100% in 2020 and to 73% in 2050. The energy self-sufficiency rate of Indonesia (another net energy exporter) will almost halve from 189% at present to 101%, barely remaining above 100%. The rates for net energy importers such as Thailand and Viet Nam will decrease further. The rate for the whole of ASEAN will plunge from 117% to 66%, turning the ASEAN region into a net energy importer.

Figure 2-23 | Net energy import changes in selected countries / regions [Reference Scenario, 2016-2050]

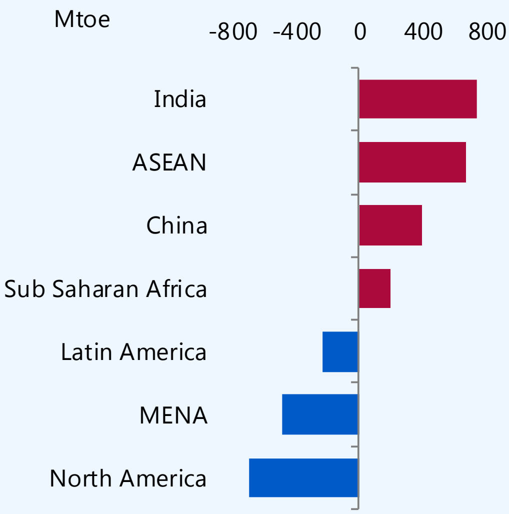
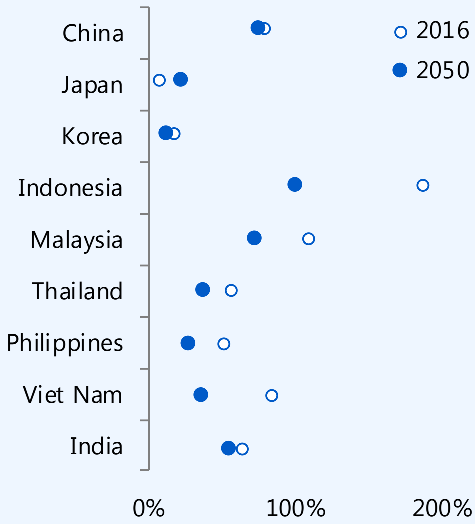


Figure 2-24 | Energy self-sufficiency rates in selected Asian countries [Reference Scenario]



In Asia, the energy self-sufficiency rate will fall from 72% in 2016 to 63% in 2050 (Figure 2-25). The self-sufficiency rate trends by fossil fuel, however, will vary widely as the resources endowment of Asia differs. According to BP Statistics (2018), the reserve-production ratio at the end of 2017 stood at 56 years for coal, compared with 32 years for natural gas and 16 years for oil. The self-sufficiency rate is anticipated to decline by 21 percentage points for natural gas, 14 points for oil and moderately for coal.

Growing fossil fuel imports will raise concerns not only about lower energy security with falling energy self-sufficiency rates, but also about the increasing economic cost through larger import payments. The value of Asia's net fossil fuel imports from other regions will expand by more than 10-fold from $390 billion (nominal value) in 2016 to $4.1 trillion in 2050 (Figure 2-26). Oil will account for more than 80% of the net import value. The value's ratio to GDP will rise from 1.6% in 2016 to 3.0% in 2050. Import price hikes as well as import volume growth will greatly contribute to the rise. Particularly, ASEAN will see the ratio of its net fossil fuel import value to GDP increasing steeply from 0.9% to 5.2%.

In the Advanced Technologies Scenario detailed in Chapter 4, progress in energy conservation and non-fossil energy expansion will restrain Asia's net fossil fuel import volume. As lower levels of global consumption will moderate hikes in international fossil fuel prices, Asia's net fossil fuel import value in 2050 would be $2.2 trillion, half the value from the Reference Scenario. The value's ratio to GDP will remain at the present level of 1.6%.

Figure 2-25 | Asian energy self-sufficiency rates [Reference Scenario]

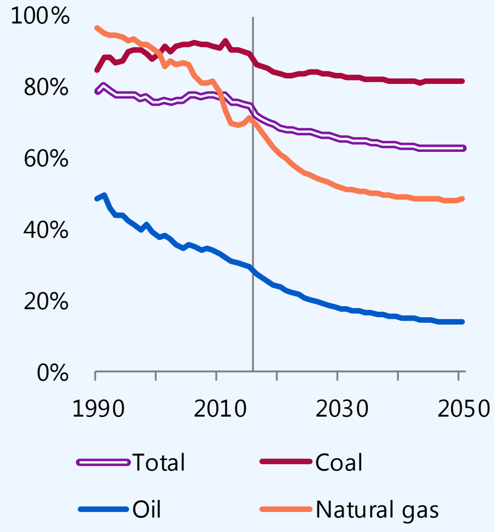
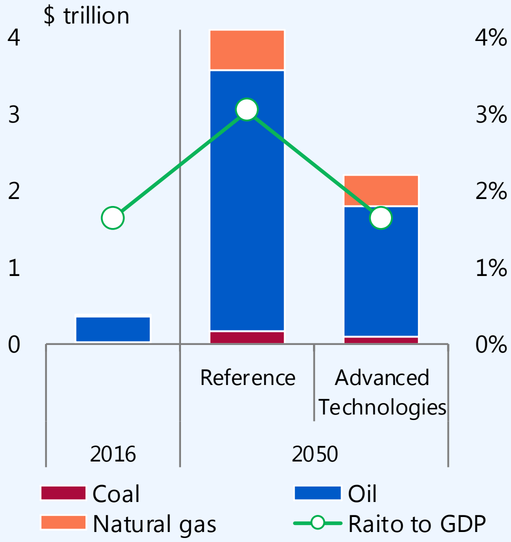


Figure 2-26 | Asian fossil fuel import value and its ratio to GDP



Given future energy security concerns, Asia should restrain its energy import volume by introducing energy conservation technologies and by proactively expanding non-fossil energy consumption. It should also develop fossil fuel stockpiling and intra-regional supply systems in preparation for contingencies. For ASEAN that will expand fossil fuel imports rapidly, particularly, the realisation of the Trans-ASEAN Gas Pipeline and ASEAN Power Grid projects would greatly contribute to the region's energy security (see Asia/World Energy Outlook 2016).

2.2 Final energy consumption

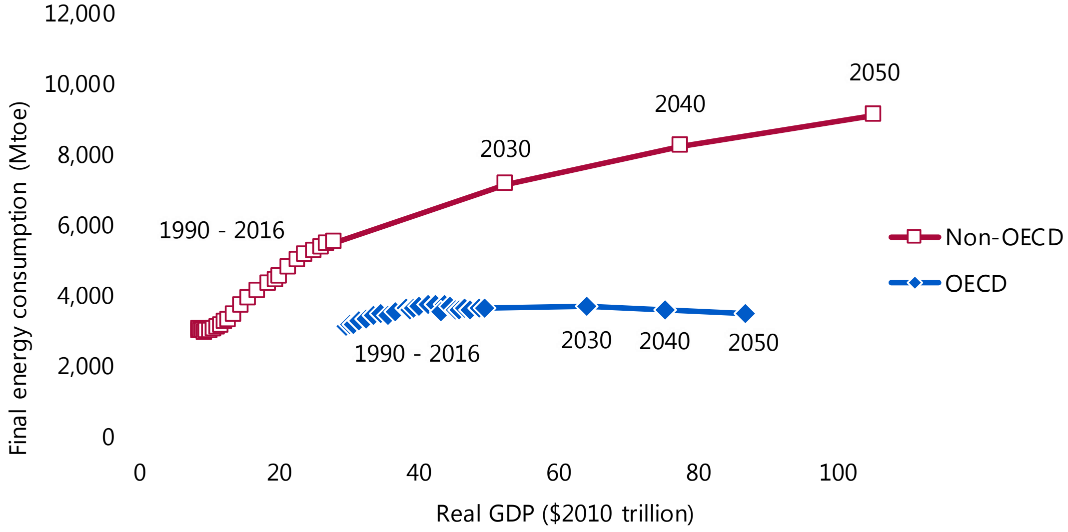
World

Final energy consumption in the world has grown at a slower pace than the world economy. Between 1990 and 2016, the annual growth in final energy consumption came to 1.6% against the annual real GDP growth rate of 2.8%[14]. Since 2010, the trend has grown even clearer with an annual final energy consumption growth limited to 1.3% compared to the average economic growth rate of 2.7%. In OECD, particularly, final energy consumption peaked in 2007 and started a downtrend due to service sectors' expansion and energy conservation, indicating the so-called decoupling between energy consumption and economic growth. In non-OECD, meanwhile, final energy consumption grew at an annual rate of 2.4% due primarily to the higher annual economic growth rate of 4.5%, increasing production in energy-intensive industries and population growth.

[14] Global total final energy consumption covers international bunkers.

As energy consumption and economic growth further decouples in OECD, OECD final energy consumption will decrease at an annual rate of 0.1% to 3,479 Mtoe, slightly less than the current level. Despite a decrease in non-OECD consumption's elasticity to GDP[15] from 0.52 (between 1990 and 2016) to 0.37 (between 2016 and 2050), due to progress in energy conservation, final energy consumption will expand 1.7-fold from the present level to 9,133 Mtoe (Figure 2-27). Global final energy consumption will increase at an annual rate of 1.0% reaching a level 40% higher in 2050 than in 2016.

Figure 2-27 | GDP and final energy consumption [Reference Scenario]

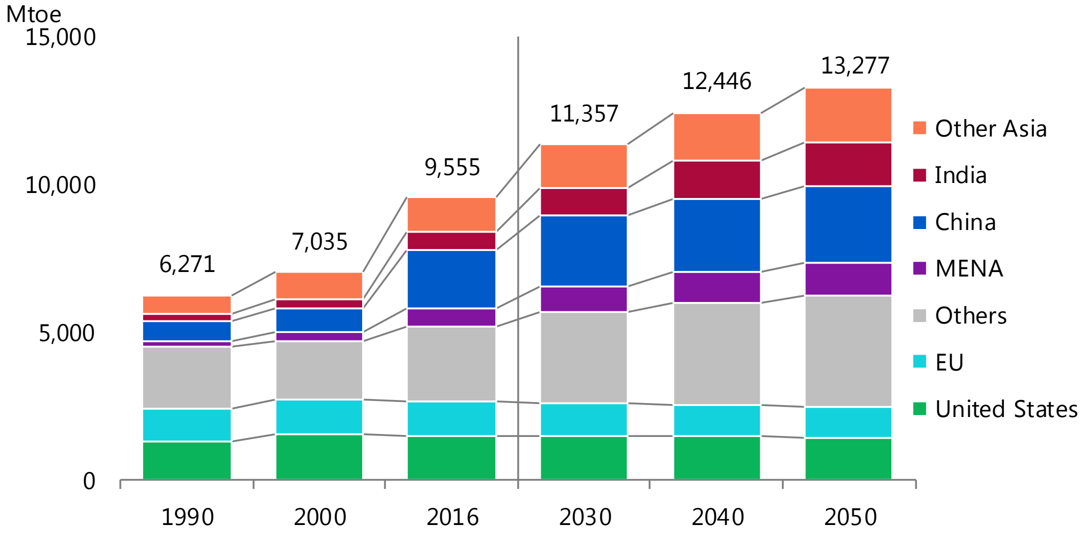


By region

Asia will account for 2,178 Mtoe or nearly 60% of the global final energy consumption growth of 3,722 Mtoe through 2050 (Figure 2-28). In Asia where high economic growth will continue against the backdrop of increasing population, final energy consumption will increase at an annual rate of 1.3% from 3,709 Mtoe in 2016 to 5,887 Mtoe in 2050 due mainly to industrial development, motorisation, urbanisation and improvements in living standards. In India that will replace China as the most populous country in the world, final energy consumption in 2050 will total 1,538 Mtoe, still short of China's consumption of 2,536 Mtoe. India, however, will remarkably expand its energy consumption, accounting for 44% of the Asian final energy consumption growth, compared with 26% for China. Nevertheless, India's per capita consumption in 2050 will be limited to 0.93 toe, still below the Asian average of 1.26 toe and the 1.89 toe for China, indicating that India would have potential to boost energy consumption further.

[15] Final energy consumption' elasticity to GDP = final energy consumption change / real GDP change.

Figure 2-28 | Final energy consumption by region [Reference Scenario]



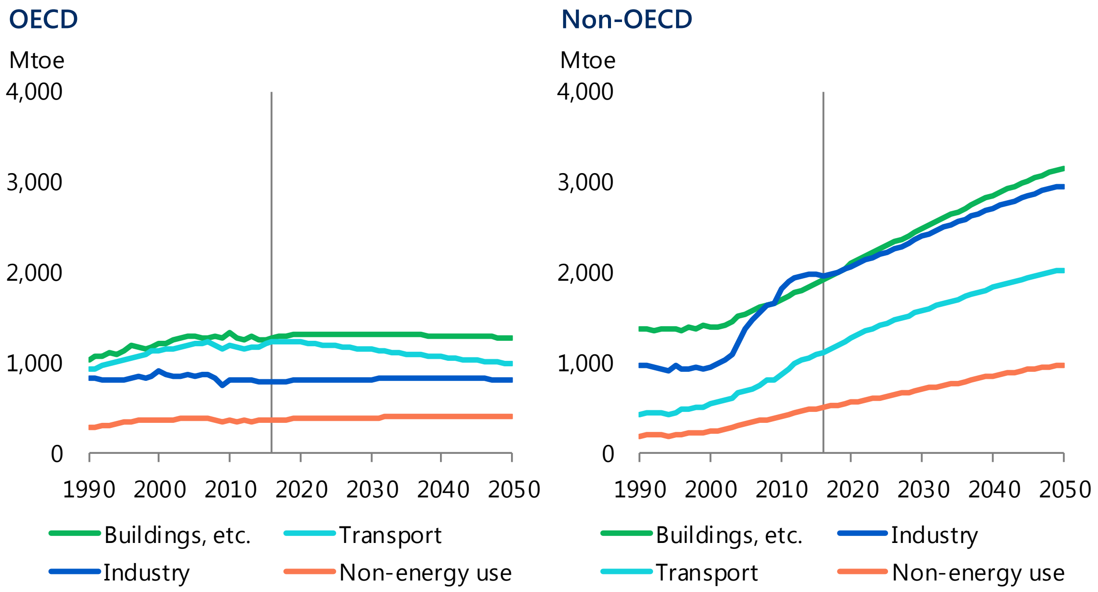
In the Middle East and North Africa (MENA), final energy consumption will grow from 627 Mtoe in 2016 to 1,134 Mtoe in 2050. The MENA growth will top the ASEAN growth, accounting for 14% of global growth. In the United States and European Union where society has matured, final energy consumption will turn downward around the 2020s, falling by 5% and 9% from the current levels, respectively.

By sector

The buildings (residential and commercial) sector will account for 1,251 Mtoe or one-third of the final energy consumption growth of 3,722 Mtoe, followed by the industry sector with an increase of 1,018 Mtoe, the transport sector with 943 Mtoe and the non-energy use sector with 509 Mtoe. The annual growth rate will be 1.4% for the non-energy use sector, 1.0% for the buildings sector and 0.9% for the industry and transport sectors. In OECD, final energy consumption will almost level off in the buildings and industry sectors but decline substantially due to automobile fuel efficiency improvements through the spread of electric vehicles in the transport sector (Figure 2-29). In non-OECD, final energy consumption will increase rapidly in each of the buildings, industry and transport sectors against the backdrop of living standard improvements and economic development.

In the buildings sector, final energy consumption will increase at an annual rate of 1.0% through 2050. Particularly, non-OECD will post an annual final energy consumption growth rate of 1.5% reflecting living standard improvements. In the buildings sector, fuel wood, livestock manure and other traditional biomass for cooking and heating in rural areas account for 24% of final energy consumption (36% in non-OECD alone). Traditional biomass consumption faces large challenges such as health issues caused by smoke and soot during burning (Box 2-2) and will be replaced with electricity, gas and other modern energy consumption in line with living standard improvements. In 2050, traditional biomass's share of final energy consumption will decline to 16% (21% in non-OECD). On the other hand, modern energy consumption will increase at an annual rate of 1.3% (2.1% in non-OECD).

Figure 2-29 | OECD and non-OECD final energy consumption [Reference Scenario]



In the transport sector, road energy consumption accounts for 75% of final energy consumption, indicating that vehicle ownership and fuel efficiency improvements hold the key to the sector's energy consumption trend. While the global vehicle fleet[16] will double from 1,360 million vehicles in 2016 to 2,720 million vehicles in 2050, electrically powered automobiles including hybrid and electric vehicles will expand their share of the vehicle ownership to 47%, leading the transport sector's final energy consumption to be limited to 1.3-fold due to substantial fuel efficiency improvements. In OECD, the transport sector's energy consumption will decrease at an annual rate of 0.6% due to smaller growth in vehicle ownership from the current already high level and substantial fuel efficiency improvements. In non-OECD, however, the sector's energy consumption will increase at an annual rate of 1.8% as an increase of more than three-fold in vehicle ownership more than offsets the effect of fuel efficiency improvements. Particularly, Asia will develop motorisation remarkably, leading non-OECD Asia to account for about 60% of global vehicle fleet growth. International bunkers (aviation and marine) will expand energy consumption at an annual rate of 1.6% on growing international travel and trade, raising their share of the transport sector's energy consumption from 15% at present to 18% in 2050.

While global manufacturing GDP will post an annual growth rate of 2.6% driven by non-OECD, the industry sector's energy consumption growth will be limited to 0.9%. Limiting energy consumption growth will be not only be the result of progress in energy efficiency technologies but also due to the sector's transition to higher value-added products and non-energy-intensive production. In China, called "the world's factory" for example, the industry sector's energy consumption will decrease at an annual rate of 0.1% despite an annual manufacturing GDP growth rate of 3.3% primarily due to the peaking in production from energy-intensive

[16] The downward pressure of progress in car sharing services on vehicle ownership growth is not considered here.

industries such as steel and cement. China's share of global industry sector energy consumption will fall from 36% at present to 26% in 2050. In contrast, the share will expand by 8 percentage points to 15% for India and by 4 points to 8% for ASEAN.

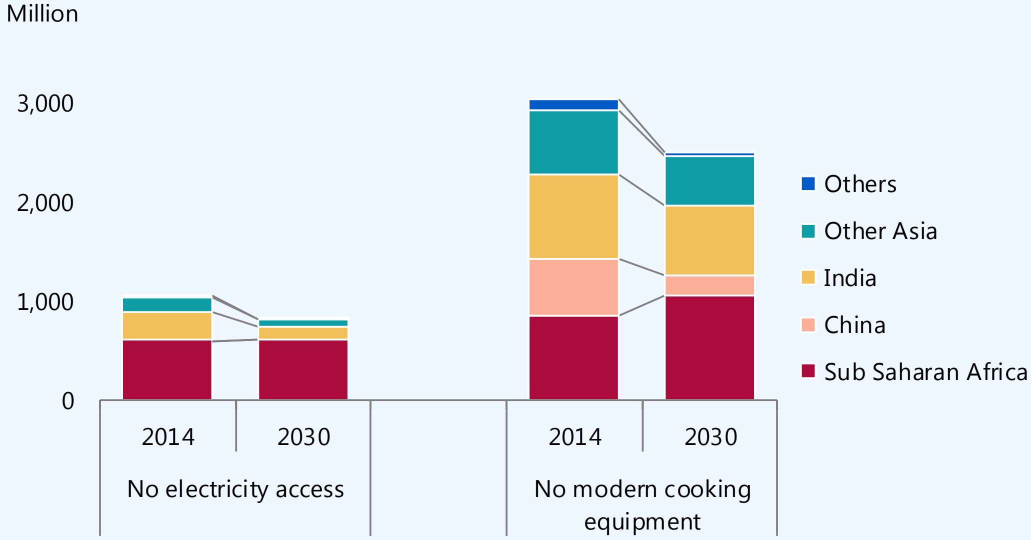
Petrochemical feedstocks account for about 70% of the non-energy use among final energy consumption. The remaining 30% includes lubricants. Given a high demand for plastics and other petrochemical products, the petrochemical industry is expected to enjoy robust growth. Particularly, non-OECD petrochemical demand and production will grow substantially, capturing more than 90% of the global growth in non-energy use. In recent years, massive plastic waste has been dumped and concerns that its flow into the water system would exert serious effects on the marine environment. Therefore, a transition is underway for biodegradable plastics that can be decomposed by living organisms and ferment into water and carbon dioxide. Given that most bioplastics are degradable, biomass is increasingly used as petrochemical material.

Box 2-2 | Energy for All

African, Asian and other rural areas still do not have a sufficient energy infrastructure. According to the World Bank's World Development Indicators, about 1.1 billion people have no access to electricity. About 3 billion people depend on fuel wood, livestock manure and other traditional biomass and coal for cooking. The problems are not limited to the inconvenient livelihood caused by poverty but include health related issues. For example, cooking using fuel wood and coal releases smoke and soot during burning that people inhale and eventually will lead to health damages. In the world, 4 million people die prematurely of such indoor environment pollution each year (World Health Organisation). The United Nations' Sustainable Development Goals (SDGs) call for "ensuring access to affordable, reliable, sustainable and modern energy for all."

IEEJ Outlook 2019 assumes the expansion of electrified areas and the substantial diffusion of modern cooking equipment. However, it envisages that about 800 million people will still have no access to electricity in 2030, the target year for attaining the SDGs, and that about 250 million people will continue cooking using fuel vulnerable to indoor pollution in 2030. This is because rural population growth will be faster than the diffusion of modern energy in Sub-Saharan Africa. The International Energy Agency (IEA) concludes that the world will have to invest $26 billion for achieving electricity access and $17 billion for diffusing modern cooking equipment annually in Sub-Saharan Africa by 2030. The African Development Bank plans to invest $12 billion and raise $50 billion from the public and private sectors by 2020 to eliminate unelectrified areas. However, the sums will fall far short of the IEA estimate. On the other hand, energy infrastructure development alone will fail to eradicate poverty. It is a concern that poor people would have access to electricity while unable to pay for it. Income improvement measures will have to be simultaneously implemented to allow poor people to afford energy. Although the U.N. SDGs give top priority to eradicating poverty, the poverty eradication will take more and more time.

Figure 2-30 | Population lacking modern energy access [Reference Scenario]



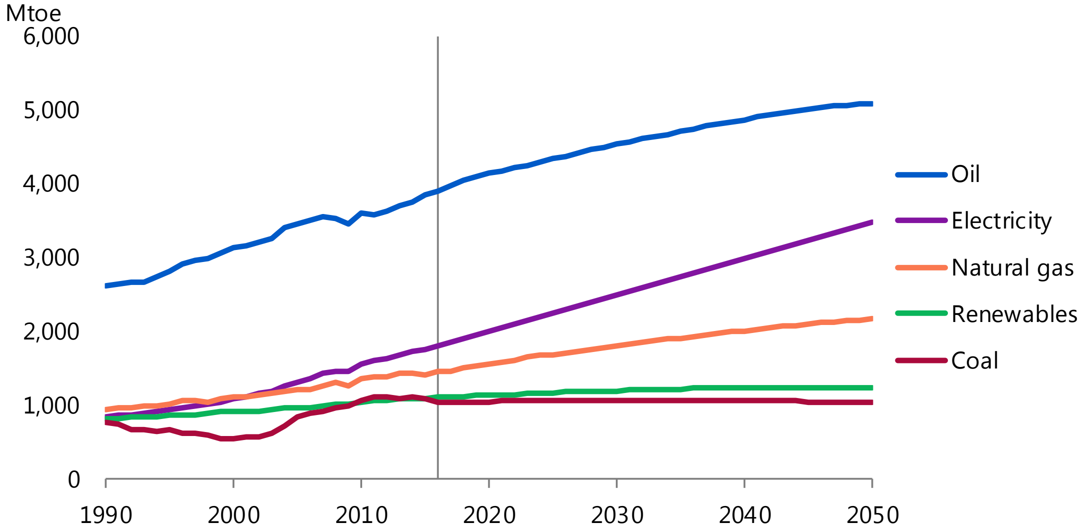
Reference: International Energy Agency "Energy Access Outlook 2017", World Health Organisation "World health statistics 2016: monitoring health for the SDGs, sustainable development goals", United Nations "Transforming our world: the 2030 Agenda for Sustainable Development", African Development Bank Group "The New Deal on Energy for Africa"

By energy source

A breakdown of final energy consumption by energy source shows that electricity will score the largest consumption growth among the different energy sources, accounting for 45% of the total final energy consumption growth in both OECD and non-OECD countries (Figure 2-31). Oil consumption will increase thanks to growth in the non-OECD transport and non-energy use sectors. Natural gas consumption will substantially expand in China's buildings sector and the Middle East's industry sector. Between 2016 and 2050, consumption will increase at an annual rate of 2.0% for electricity, at 1.2% for natural gas and at 0.8% for oil. Meanwhile, coal consumption peaked in 2014 and will almost level off in the future. The share of total energy consumption will rise from 19% to 26% for electricity and from 15% to 16% for natural gas, while falling from 41% to 38% for oil and from 11% to 8% for coal.

Of the final oil consumption, the transport sector accounts for 65% (including 49% for the road sector and 10% for international bunkers), the non-energy use sector for 17% and the buildings sector for 11%. Among these sectors, the transport sector will post the largest oil consumption growth, followed by the non-energy use sector. The Asian automobile fuel consumption will drive the oil demand growth, fully offsetting a decline in OECD oil consumption. In Asian developing countries including China, India and ASEAN members, vehicle ownership will increase rapidly on progress in motorisation amid income improvements. Asia will command nearly 60% of final energy consumption growth in the non-energy use sector and will capture about 70% of the global final oil consumption growth through 2050, boosting its share of global oil consumption from 31% in 2016 to 40% in 2050. International bunkers will also sharply expand energy consumption on growing international travel and trade, raising their share of final oil consumption to 12%.

Figure 2-31 | Global final energy consumption (by energy source) [Reference Scenario]



Of final natural gas consumption, the buildings sector accounts for 44% (30% for the residential sector and 13% for the commercial sector), the industry sector for 37% and the non-energy use sector for 12%. Among these sectors, the industry sector will post the largest growth in future natural gas consumption, followed by the non-energy use sector and the buildings sector. Asia will capture 51% of the industry sector consumption growth and 35% of the non-energy use sector consumption growth. Asia is followed by the Middle East commanding 26% of industry sector consumption growth and 21% of non-energy use sector consumption growth. The Middle East is promoting domestic natural gas utilisation to earn foreign currencies with oil exports and expanding petrochemical plants using natural gas to generate jobs. China's buildings sector will account for 17% of the global final natural gas consumption growth. China's residential sector still uses massive coal and biomass fuels such as fuel wood and is rapidly switching to city gas to limit indoor and outdoor air pollution.

Generally, people favour the convenience of electricity as their income grows and this trend will remain unchanged. Electricity will score the highest consumption growth among major energy sources both in OECD and non-OECD. The global electrification rate (on the consumption side)[17] will rise from 19% in 2016 to 26% in 2050. Driving this growth will be Asia including China, India and ASEAN. China, the largest electricity consumer in the world, will expand electricity consumption by 4,687 TWh, exceeding the current consumption of 3,807 TWh of the United States, the second largest electricity consumer in the world. India will increase its electricity consumption by 3,992 TWh, becoming an electricity market rivalling the United States in 2050. Both China and India thus will rapidly boost electricity consumption. Non-OECD electricity consumption will account for 85% of global electricity consumption growth. Particularly, the buildings sector will command 55 percentage points of the share

[17] The rate is the ratio of electricity consumption to total final energy consumption.

(Figure 2-32). Households will capture more than 50% of the sector's electricity consumption growth. Electricity infrastructure development in unelectrified rural areas and the penetration of convenient electrical home appliances will induce the consumption growth. In OECD where most electrical home appliances have diffused sufficiently, residential electricity consumption will increase little due to progress in equipment and insulation efficiency, although some oil and gas appliances will be replaced with electrical products. In non-OECD, the diffusion of electric water heaters, air conditioners, lighting equipment, refrigerators and other electrical home appliances will boost electricity consumption (Figure 2-33).

Figure 2-32 | Final electricity consumption [Reference Scenario]

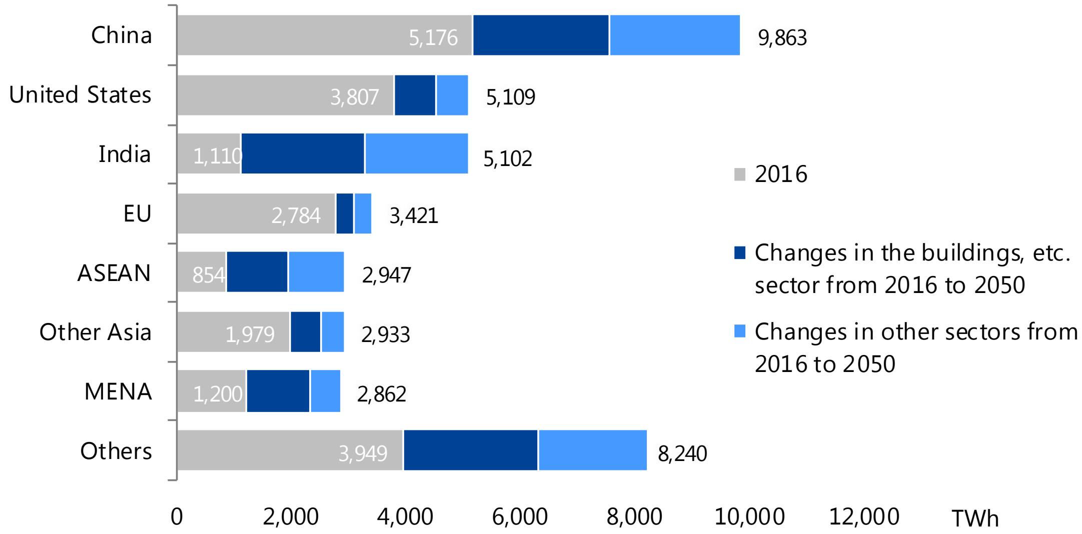
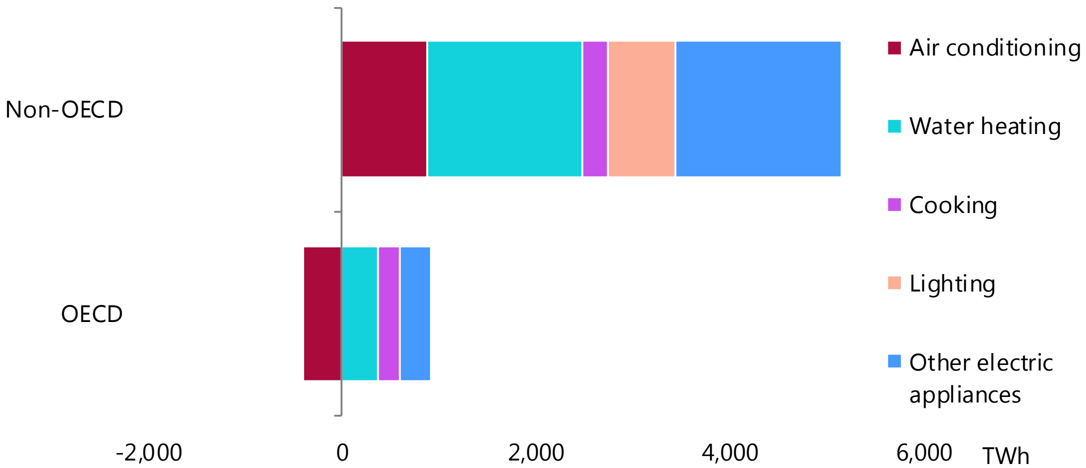


Figure 2-33 | Changes in residential electricity consumption [Reference Scenario, 2016-2050]



As dependence on electricity for economic activities and daily life grows, the impact of electricity supply disruptions increases. As the risk of new electricity supply disruptions is increasing due to the massive expansion of intermittent electricity sources and potential cyberattacks, technological and institutional preparations for supply disruptions are growing more important (see "Chapter 6 Risk and impact of energy supply disruptions").

The industry sector accounts for about 80% of the final coal consumption and China alone captures about 70% of the coal consumption. While China's industrial coal consumption will post a steep decline of about 40% by 2050, due to peaking steel and cement production, India and ASEAN will expand their coal consumption. As a result, global final coal consumption will almost level off (decreasing at an annual rate of 0.04%). Given that many industries are making a transition from coal to electricity or gas and because coal, though cheaper, is inferior to other energy sources in environmental friendliness, no large growth in coal consumption can be expected. China with abundant coal resources is growingly using coal as petrochemical feedstocks to restrain oil imports.

Fuel wood, livestock manure and other traditional biomass used in rural areas of developing countries account for about three quarters of the final renewable energy consumption. The remaining 25% is comprised of fuel wood (mainly for fireplaces in Western countries) for a little more than 10%, biofuels (for vehicles) for a little less than 10%, and solar and geothermal energy utilisation for the rest. Traditional biomass consumption will continue increasing due to rural population growth before peaking in the mid-2030s on the improvement of access to modern energy.

3. Energy supply

3.1 Crude Oil

Production

In the Reference Scenario, both OPEC and non-OPEC crude oil production will increase in line with robust oil consumption growth (Table 3-1). While Asian countries among non-OPEC oil producers will reduce production through 2030, U.S. shale oil (light tight oil) production will strongly increase on firm investments in oil exploration and development associated with moderate crude oil price hikes. Latin American oil production will also expand, including pre-salt oil production in Brazil. The non-OPEC share of global oil production will increase slightly from 57% in 2016 to 58% in 2030. Oil production growth in the Americas (including Canada expected to boost unconventional oil production), will account for 77% of the global oil production growth through 2030.

Table 3-1 | Crude oil production [Reference Scenario]

(Mb/d)

	2016	2030	2040	2050	2016-2050	
					Changes	CAGR
Crude oil production	92.0	102.8	110.2	114.5	22.5	0.6%
OPEC	39.9	43.6	50.2	54.4	14.6	0.9%
Middle East	30.6	34.1	38.4	41.2	10.6	0.9%
Others	9.3	9.5	11.7	13.3	4.0	1.1%
Non-OPEC	52.2	59.2	60.0	60.0	7.9	0.4%
North America	16.8	23.6	23.0	21.6	4.8	0.7%
Latin America	6.9	8.5	10.5	11.8	4.8	1.6%
Europe / Eurasia	17.7	16.9	16.3	16.2	-1.5	-0.3%
Middle East	1.3	1.5	1.6	1.7	0.5	0.9%
Africa	1.3	1.6	1.7	1.8	0.5	0.9%
Asia and Oceania	8.0	7.1	7.0	6.9	-1.1	-0.5%
Processing gains	2.3	2.8	3.2	3.4	1.1	1.2%
Biofuels	2.2	3.1	3.5	3.9	1.7	1.7%
GTL and CTL	0.3	0.9	1.0	1.1	0.8	4.0%
Liquid fuel supply	96.9	109.7	117.9	123.0	26.1	0.7%

As shale oil production declines later and European and Eurasian production peaks out around 2030, the non-OPEC share will fall to 52% in 2050. OPEC will capture 93% of global crude oil production growth between 2030 and 2050, driven by Saudi Arabia with spare production capacity and Iran and Iraq with production expansion potential.

Trade

Global crude oil trade totalled 42 Mb/d in 2017 (Figure 3-1). Major importers are Asia (Japan, Korea, Chinese Taipei, China, Southeast Asia and South Asia), OECD Europe and North

America. Major suppliers are the Middle East, Africa and Latin America for Asia, non-OECD Europe and Central Asia for OECD Europe, and Latin America and the Middle East for North America.

Crude oil trade will increase slightly to 43 Mb/d in 2030. Less oil imports will be required in OECD countries and in North America, due to either a demand decline or a production increase. More imports will be needed to meet the growing demand in Asian emerging economies and they will drive the global trade growth (Figure 3-2).

Asia will diversify its crude oil supply sources by expanding imports from North America, non-OECD Europe and Central Asia. The Middle East and Africa will, however, still account for 80% of Asian crude oil supply in 2030. From 2017 to 2030, North America will increase its domestic crude oil production and therefore will reduce its import needs but will continue to import from Latin America and the Middle East. North America, non-OECD Europe, Central Asia, Africa and the Middle East will compete for exports to the shrinking European market. Non-OECD Europe, Central Asia and the Middle East will progressively shift towards the Asian growing demand, while decreasing their supply to Europe. Meanwhile, North America will increase crude oil production and exports to Europe.

Figure 3-1 | Major crude oil trade flows [2017]

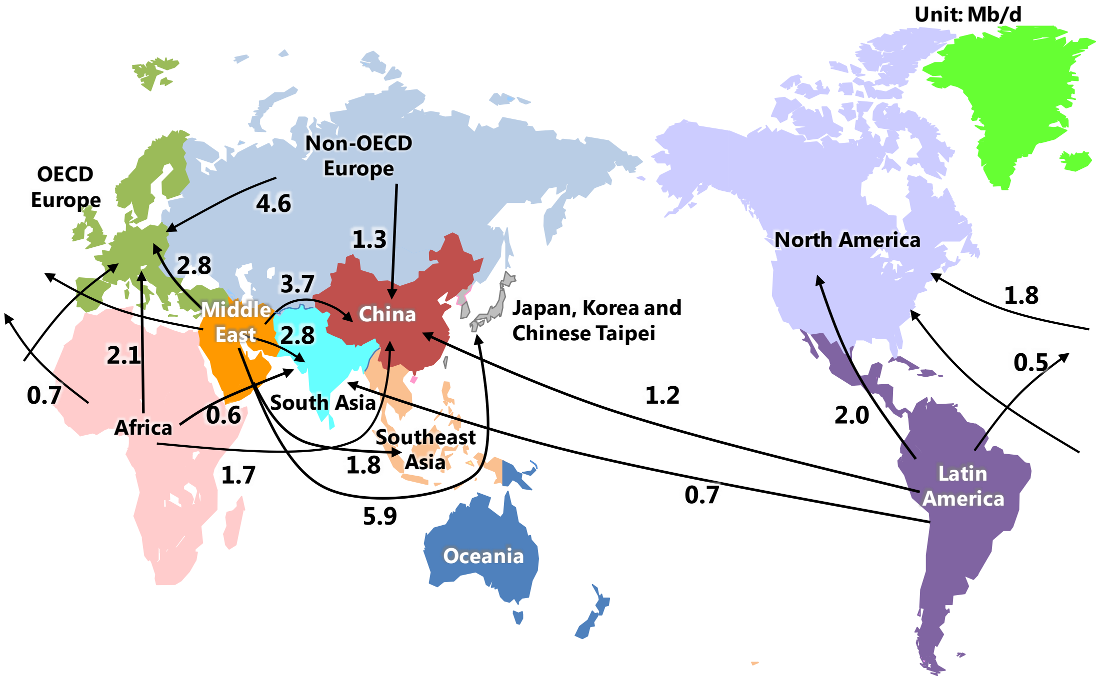
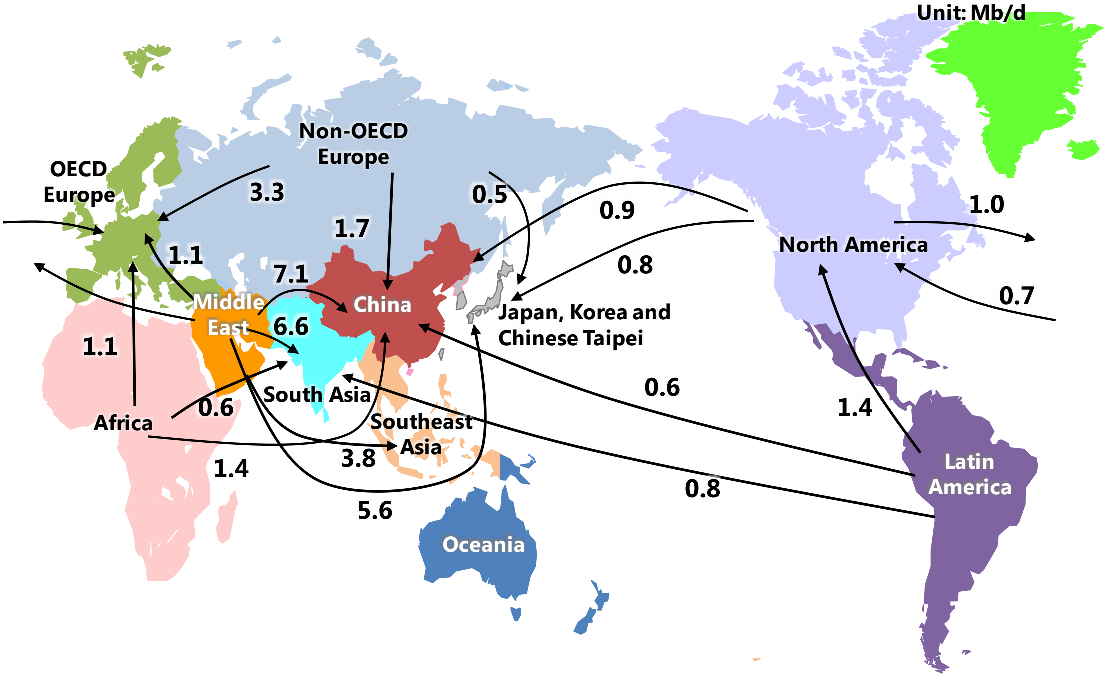


Figure 3-2 | Major crude oil trade flows [Reference Scenario, 2030]



3.2 Natural gas

Production

Global natural gas production will grow about 1.7-fold from 2016 to 2050 (Table 3-2). Although upstream investments slumped in 2014, due to weak crude oil prices, they have recently recuperated with the oil price recovery of 2017, leading natural gas production to embark on a steady uptrend.

North American production will increase robustly, including production in the Permian area in the South of the United States and in the Marcellus Shale in the Northeast. In Canada, shale and other gas resources development will make progress in line with LNG project implementation on the west coast.

Production will increase in Non-OECD Europe, Russia and Turkmenistan, rich with gas resources. Russia will particularly promote new gas field developments mainly on the Arctic coast and in Eastern Siberia. In the Middle East, Iran's natural gas development will stagnate at least temporarily due to the U.S. Trump administration's withdrawal from the Iran nuclear deal and resumption of economic sanctions on the country. Over a long term, however, the Middle East will expand natural gas production to meet the growth in local consumption and LNG exports. In Asia, China and India will promote natural gas development to satisfy a growing domestic demand.

Table 3-2 | Natural gas production [Reference Scenario]

(Bcm)

	2016	2030	2040	2050	2016-2050	
					Changes	CAGR
World	3,502	4,595	5,345	5,987	2,485	1.6%
North America	901	1,216	1,283	1,390	489	1.3%
Latin America	199	284	388	461	262	2.5%
OECD Europe	245	221	210	186	-58	-0.8%
Non-OECD Europe / Central Asia	790	968	1,096	1,226	436	1.3%
Russia	599	713	798	883	284	1.1%
Middle East	610	784	922	1,090	480	1.7%
Africa	211	334	480	516	305	2.7%
Asia	466	603	734	861	396	1.8%
China	133	237	343	413	280	3.4%
India	30	58	83	105	75	3.7%
ASEAN	213	218	228	263	50	0.6%
Oceania	81	185	232	257	176	3.4%

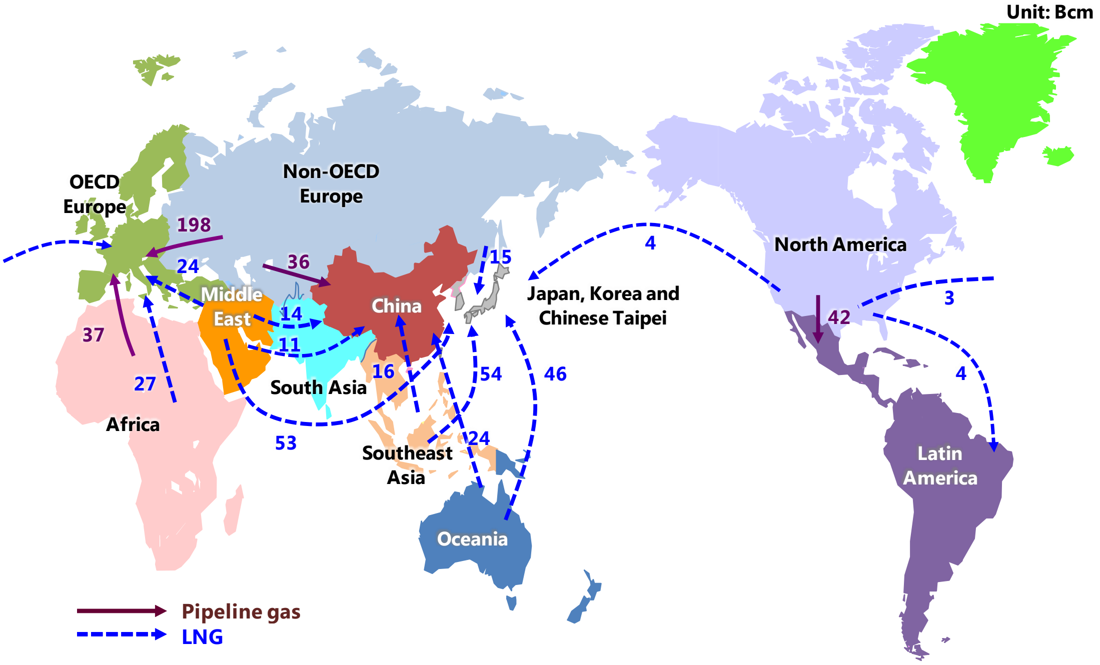
As China expands shale and other unconventional natural gas resources that are more difficult to develop, the extent to which domestic gas development could be promoted will attract attention. In Africa, such countries as Mozambique, Senegal and Tanzania will increase gas production as new LNG projects are implemented.

Trade

Natural gas trade between major regions in the world totalled 631 billion cubic metres in 2017. Pipeline gas trade accounted for about half the total, including Russian pipeline gas exports to Europe that captured most pipeline trade. LNG trade has been primarily limited to exports from Southeast Asia to Northeast Asia including Japan and Korea. Recently, however, global LNG trade flows have diversified and become complicated as production under new LNG projects has started in the United States, Australia and other countries. New LNG terminals are under construction in Southeast Asia, Latin America, Europe, the Middle East and other regions.

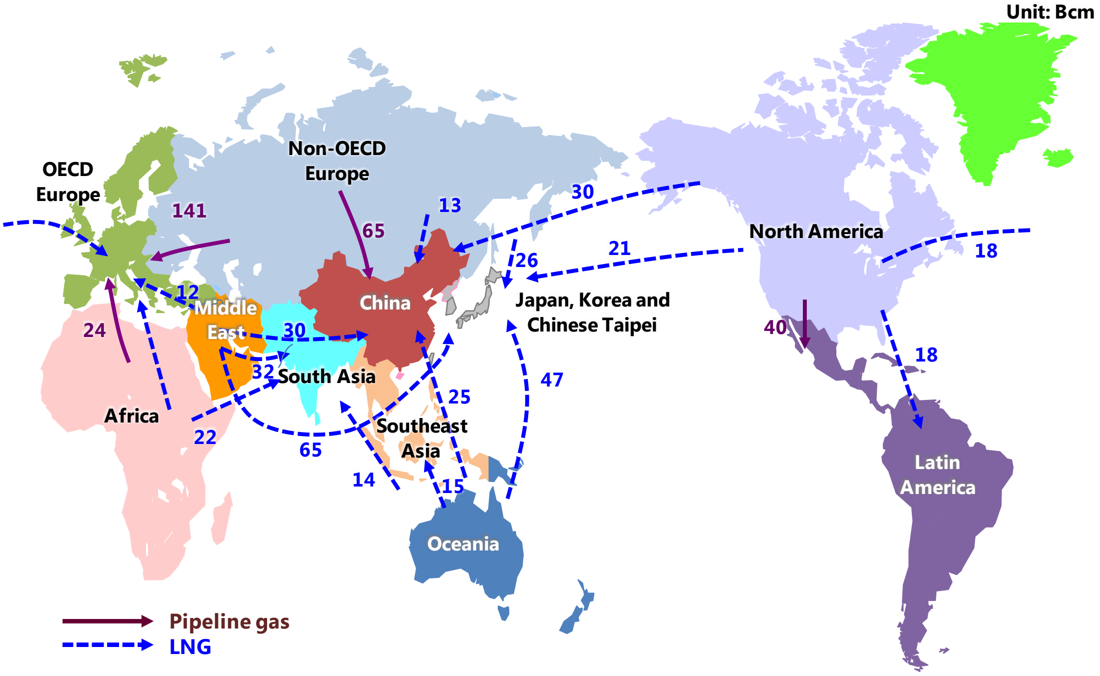
Natural gas trade between major regions will increase to 800 Bcm by 2030. North America and the Middle East will post the largest export growth. In North America, the United States is set to dramatically expand LNG exports, with Canada also planning new LNG export projects. In the Middle East, Qatar plans to expand LNG production capacity from 77 million tonnes at present to 100 Mt by 2024. Non-OECD Europe including Russia and Central Asia will remain the world’s largest natural gas export base, expanding not only traditional pipeline exports to Europe but also pipeline exports to China and LNG exports under new projects.

Figure 3-3 | Major natural gas trade flow [2017]



Source: BP "BP Statistical Review of World Energy" (2018)

Figure 3-4 | Major natural gas trade flow [Reference Scenario, 2030]

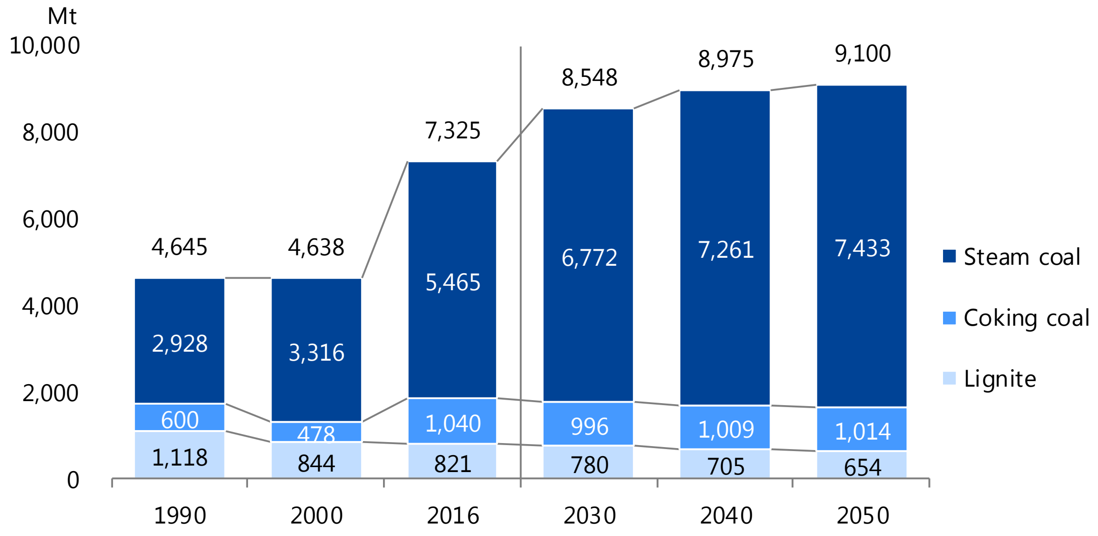


3.3 Coal

Production

Global coal production will increase from 7,325 Mt in 2016 to 9,100 Mt in 2050 as coal consumption expands in non-OECD, mainly in Asia, Latin America and Africa. However, the production growth will gradually diminish overtime (Figure 3-5). Steam coal production will rise 1.36-fold from 5,465 Mt in 2016 to 7,433 Mt in 2050 due to growing demand for power generation, while coking coal production will decrease slightly from 1,040 Mt in 2016 to 1,014 Mt in 2050. Lignite production will also decline from 821 Mt in 2016 to 654 Mt in 2050.

Figure 3-5 | Global coal production by type [Reference Scenario]



By region, coal production will increase in Asia featuring growing coal consumption and in Oceania, Africa, Latin America, non-OECD Europe and Central Asia that have major coal exporting countries. However, production will decrease in North America and OECD Europe where coal consumption will decline (Table 3-3).

Asian coal production will grow from 4,600 Mt in 2016 to 6,332 Mt in 2050. In China, the world's largest coal consumer and producer, coal consumption has been on a downtrend in recent years due to air pollution countermeasures. In the future, steam coal production will rise slightly as demand will moderately increase reflecting higher consumption for power generation, however, the growth will gradually decelerate before turning negative around 2035. Meanwhile, coking coal production will decline as consumption falls on a decline in pig iron production. Endowed with abundant coal resources, India is stepping up efforts to expand production and will increase steam and coking coal production in conjunction with consumption growth. Given the high ash content of the indigenous resources and a lack of transport infrastructure development to connect the coal mines with where the demand is, production in India will fall short of satisfying the growing demand with domestic production alone. In Indonesia, coal production peaked in 2013 because of weak international coal prices and drops in Chinese and Indian imports. As the Indonesian government has come up with plans to adjust (cap) coal production to protect coal resources and use them sustainably and efficiently, however, production growth will be limited to a moderate level. It will increase in the future on domestic consumption growth.

Table 3-3 | Coal production [Reference Scenario]

Steam coal production (Mt)

	2016	2030	2040	2050	2016-2050	
					Changes	CAGR
World	5,465	6,772	7,261	7,433	1,968	0.9%
North America	571	476	369	271	-299	-2.2%
United States	544	473	365	266	-278	-2.1%
Latin America	101	140	171	195	94	2.0%
Colombia	86	124	154	176	89	2.1%
OECD Europe	72	68	57	48	-24	-1.2%
Non-OECD Europe and Central Asia	324	363	420	460	136	1.0%
Russia	209	256	304	344	135	1.5%
Middle East	0	0	0	0	0	1.1%
Africa	258	315	352	376	118	1.1%
South Africa	252	294	318	328	76	0.8%
Asia	3,889	5,063	5,439	5,545	1,656	1.0%
China	2,721	3,237	3,273	3,085	364	0.4%
India	609	1,171	1,506	1,793	1,184	3.2%
Indonesia	460	552	552	552	92	0.5%
Oceania	251	346	453	538	287	2.3%
Australia	250	345	452	537	288	2.3%

Coking coal production (Mt)

	2016	2030	2040	2050	2015-2050	
					Changes	CAGR
World	1,040	996	1,009	1,014	-26	0.0%
North America	75	66	67	64	-11	-0.3%
United States	50	42	43	41	-9	-0.5%
Latin America	9	10	10	10	1	0.4%
Colombia	4	5	5	5	1	0.6%
OECD Europe	20	17	16	15	-5	-0.7%
Non-OECD Europe and Central Asia	110	107	107	107	-3	0.1%
Russia	84	77	76	75	-9	-0.2%
Middle East	1	1	1	1	0	0.0%
Africa	8	14	18	22	14	3.8%
Mozambique	4	11	15	19	15	4.8%
Asia	627	590	585	583	-44	-0.3%
China	547	459	424	394	-153	-1.2%
India	57	108	140	168	111	3.7%
Mongolia	20	17	16	15	-5	-0.8%
Oceania	190	192	205	212	22	0.8%
Australia	189	191	203	210	21	0.8%

North American coal production will decrease sharply from 722 Mt in 2016 to 365 Mt in 2050. U.S. and Canadian steam coal production will decline due to falling domestic consumption. Coking coal production, though depending on international prices, will decrease as major export destinations OECD Europe and East Asia reduce imports.

In OECD Europe, both steam and coking coal production will fall due to production cost hikes, lower domestic demand, and the elimination of subsidies for the coal industry in 2019 in some countries. Consumption will also decline in non-OECD Europe and Central Asia. Russia, however, will expand steam coal production due to growing exports to Asia.

In Africa, coal production will rise from 266 Mt in 2016 to 400 Mt in 2050 in line with growth in regional steam coal consumption and export demand (including growing Asian steam and Indian coking coal demand). In South Africa, steam coal production will increase while Mozambique will expand both coking and steam coal production.

Latin America will increase coal production due to expanding local consumption and exports. Colombia, a major steam coal exporter, will double production from 86 Mt in 2016 to 176 Mt in 2050 on the expansion of the Asian market as well as exports to Africa, South America and the Middle East, while the European market, its major export destination, will shrink.

In Oceania, Australia will raise coal production sharply. Its steam coal production will increase substantially from 250 Mt in 2016 to 537 Mt in 2050 to meet the expansion of the Asian market and make up for a decline in exports from Indonesia.

Trade

Coal trade (import volume) will expand from 1,318 Mt in 2016 to 1,738 Mt in 2050 in line with consumption growth (Figure 3-6). Steam coal trade will increase from 1,034 Mt in 2016 to 1,406 Mt in 2050 in response to consumption growth mainly in India and Southeast Asia. Coking coal trade will grow from 279 Mt in 2016 to 329 Mt in 2050 due mainly to increasing Indian consumption.

In steam coal trade, imports in Asia will increase by 409 Mt from 748 Mt in 2016 to 1,157 Mt in 2050. Among other regions, imports will expand by 26 Mt in Latin America, by 18 Mt in Africa and by 5 Mt in the Middle East. Among Asian countries, India and four major ASEAN members (Malaysia, Thailand, the Philippines and Viet Nam) will substantially expand imports. Of the increase in Asian steam coal imports, India will account for 165 Mt and the four major ASEAN members for 159 Mt. Meanwhile, OECD Europe will reduce imports from 188 Mt in 2016 to 113 Mt in 2050 due to a consumption drop. On the supply side, exports will increase from Australia, South Africa, Russia and Colombia. Indonesia will reduce exports over a medium to long term due to production adjustments and domestic consumption growth. In South Africa, new coal mines are being developed in preparation for the depletion of resources at present major production areas. Given constraints on production expansion as well as domestic consumption growth, however, exports will peak at around 90 Mt.

In coking coal trade, India will increase imports sharply from 47 Mt in 2016 to 119 Mt in 2050 and Brazil will raise imports by 9 Mt. Due to consumption drops, however, China will reduce imports by 11 Mt and OECD Europe by 17 Mt. Japan, Korea and Chinese Taipei will also cut imports by a combined 11 Mt. On the supply side, Australia and Mozambique will expand exports. As imports decline in China, Japan and Korea, however, exports from the United States and Mongolia will decrease.

Figure 3-6 | Global coal trade (Import volume) [Reference Scenario]

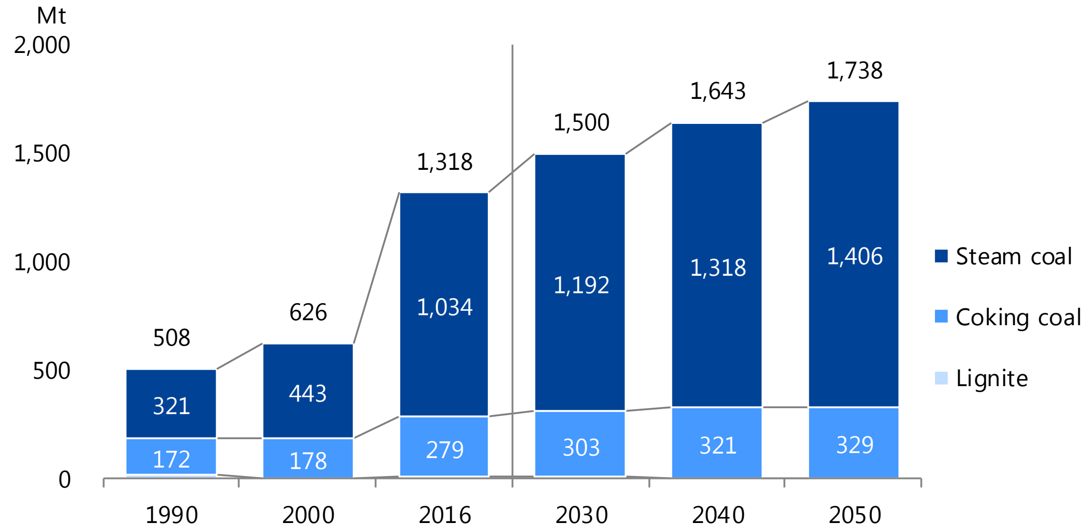
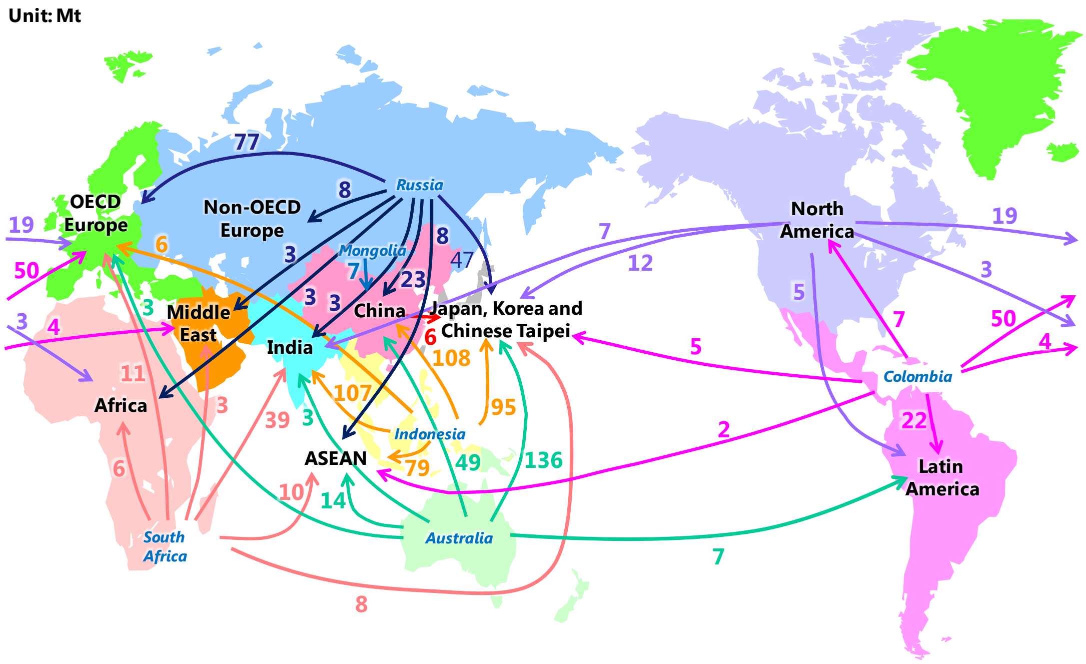


Figure 3-7 | Major steam coal trade flows [2017]

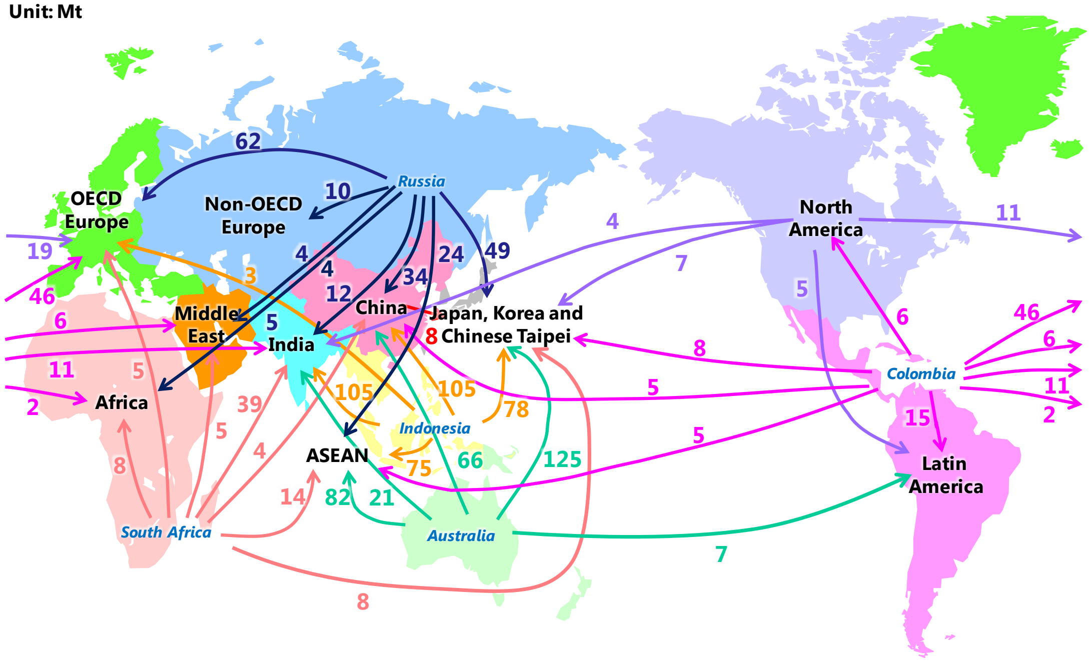
Unit: Mt



Note: Estimated imports totalling 2 Mt or more are specified.
Source: IEA "Coal Information 2018"

Figure 3-8 | Major steam coal trade flows [Reference Scenario, 2030]

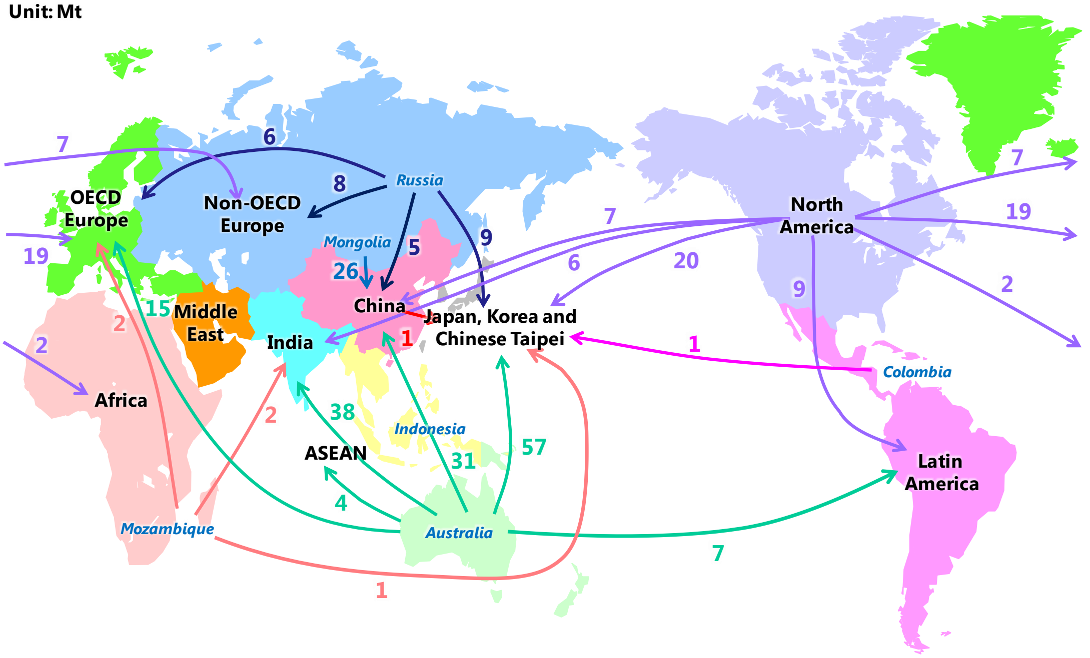
Unit: Mt



Note: Estimated imports totalling 2 Mt or more are specified.

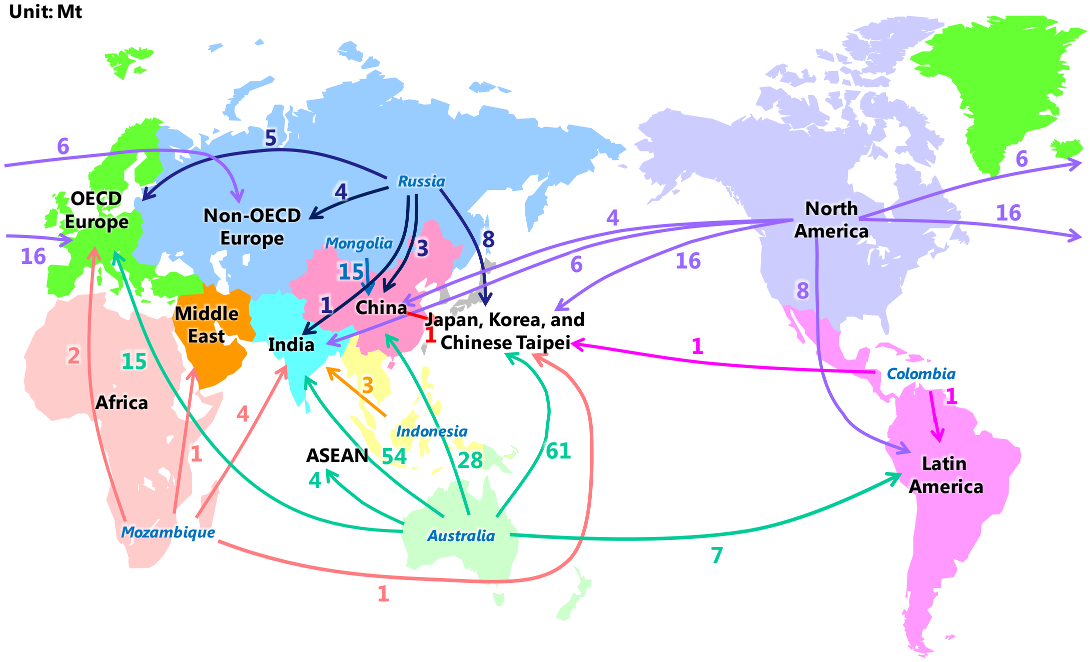
Figure 3-9 | Major coking coal trade flows [2017]

Unit: Mt



Note: Estimated imports totalling 1 Mt or more are specified.
Source: IEA “Coal Information 2018”

Figure 3-10 | Major coking coal trade flows [Reference Scenario, 2030]



Note: Imports totalling 1 Mt or more are specified.

3.4 Power generation

Power generation and its mix

In line with electricity consumption growth, global power generation will increase at an annual rate of 1.9% to 46,915 terawatt-hours (TWh) in 2050, up 1.9-fold from 2016 (Figure 3-11). The increase of 21,942 TWh from 2016 to 2050 is 3.6 times as large as the current power generation in China, known as the world's largest electricity generator. Of the increase, non-OECD will account for about 90%. In Asia, subject to rapid economic growth, power generation will rise at an annual rate of 2.4% from 10,768 TWh in 2016 to 23,994 TWh in 2050 (Figure 3-12).

Figure 3-11 | Global power generation and final consumption [Reference Scenario]

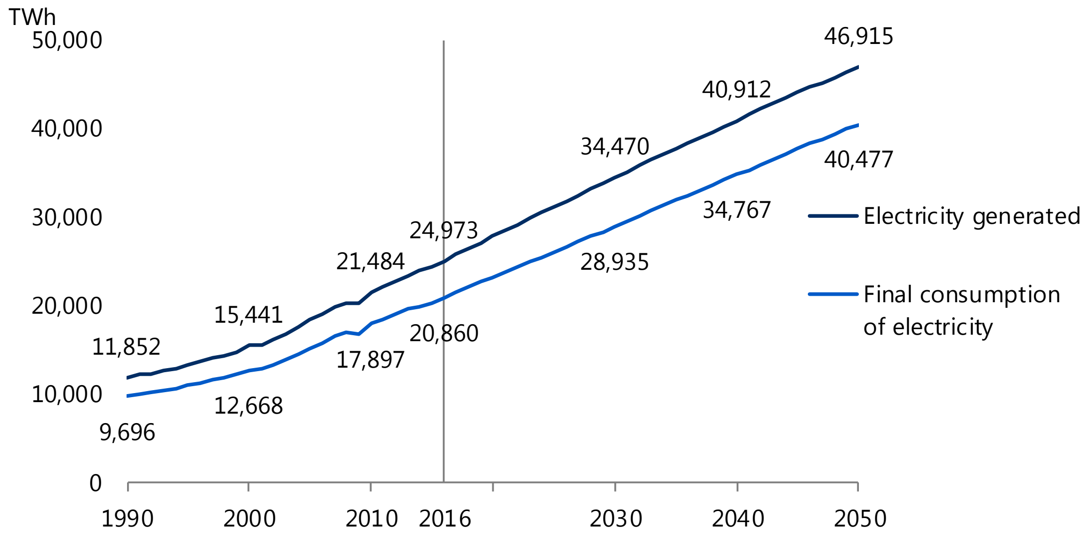
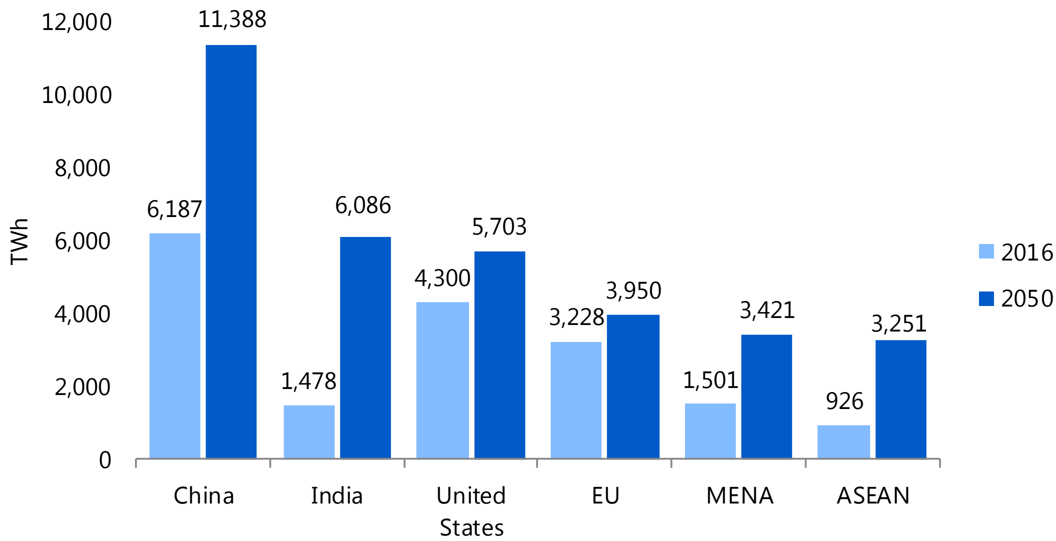
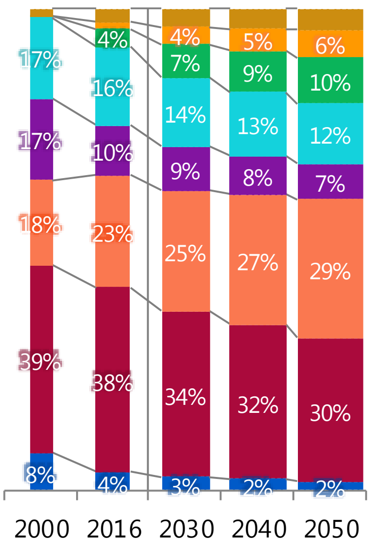


Figure 3-12 | Power generation in selected countries / regions [Reference Scenario]

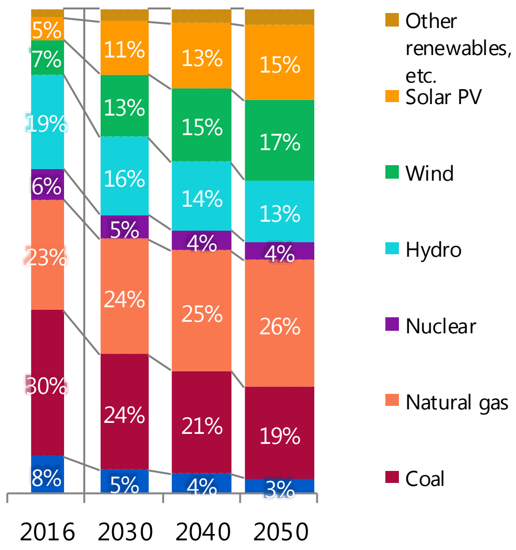


Coal accounted for the largest share of global power generation in 2016, followed by natural gas, hydro and nuclear (Figure 3-13). Through 2050, coal's share, though declining, will remain the largest, with coal continuing to serve as a baseload electricity source. As technological development allows highly efficient combined cycle gas turbines (CCGTs) to diffuse, with gas turbines used to adjust for variable / intermittent renewable energy generation, natural gas's share of the electricity mix will expand from 23% in 2016 to 29% in 2050. The share for oil will trend down in developed countries as well as in the oil-rich Middle East. Nuclear power plant construction will make progress mainly in Asia as a measure to ensure energy security and mitigate climate change. Nuclear power generation growth will, however, fail to exceed electricity demand growth through 2050. The nuclear share of power generation will thus fall to 7% in 2050. Wind, solar photovoltaics and other renewable energy generation, excluding hydropower generation, will expand at a rapid annual rate of 5.1% on the strength of policy support and cost reduction, boosting its electricity mix share to about 20% in 2050. Natural gas will gradually increase its share of global installed power generation capacity through 2050, replacing coal as the largest electricity source.

Figure 3-13 | Global power generation mix [Reference Scenario]



Note: Bar widths are proportionate to total power generation.



Note: Bar widths are proportionate to total power generation capacity.

In OECD, renewable energy's share of total power generation in 2030 will top 30%, replacing the natural gas share as the largest one. Under a policy of shifting away from coal-fired power generation, coal's share will substantially decline from currently the largest to a little more than 10% in 2050. In non-OECD, coal's share of total power generation will continuously fall from now on but will remain the largest even in 2050. Financing measures and solutions to air pollution and other environmental problems will be urgently required to meet the robust non-OECD electricity demand with coal-fired power generation. Natural gas and renewable energy will expand their respective shares to nearly 30% in 2050, becoming major power sources (Figure 3-14).

In Asia including China and India, coal will remain a mainstay power source in response to the rapid electricity demand growth. However, its high share of the power generation mix will fall gradually, while nuclear, renewable energy and natural gas will expand theirs (Figure 3-15). Meanwhile, ASEAN has made a great shift from oil to natural gas as power generation fuel since the 1990s due to natural gas development in the Bay of Thailand and other locations. Since natural gas production peaked out and natural gas demand emerged in other sectors than power generation in the 2000s, however, natural gas availability for power generation has become in short supply. When ASEAN will no longer be a net natural gas exporter, it will go forward with plans to import natural gas. However, natural gas's share of ASEAN power generation will decrease with the coal share increasing.

Figure 3-14 | OECD and non-OECD power generation mix [Reference Scenario]

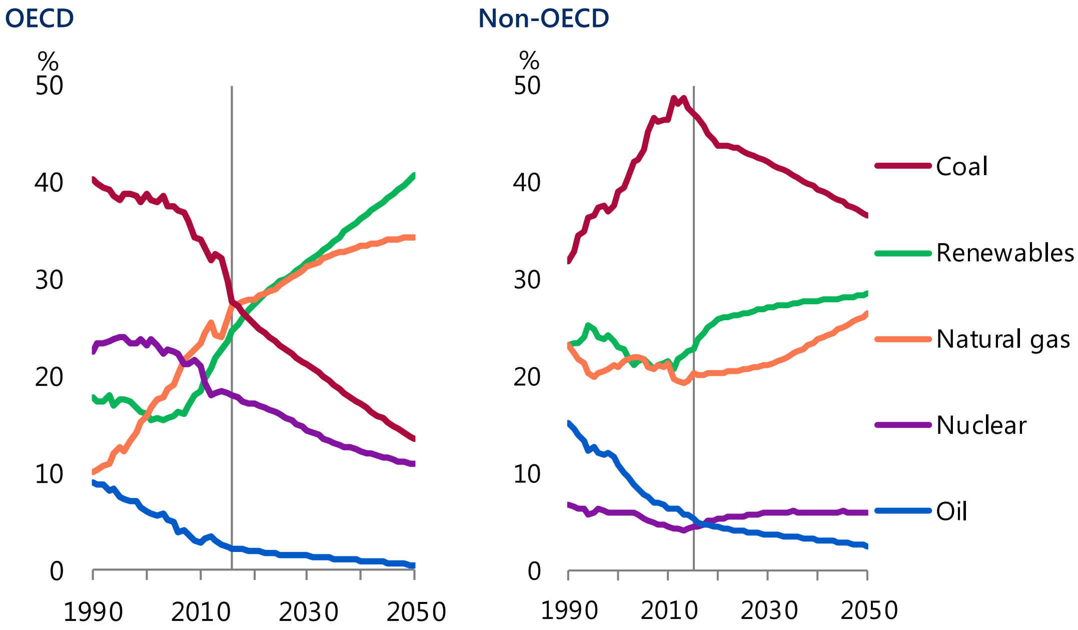
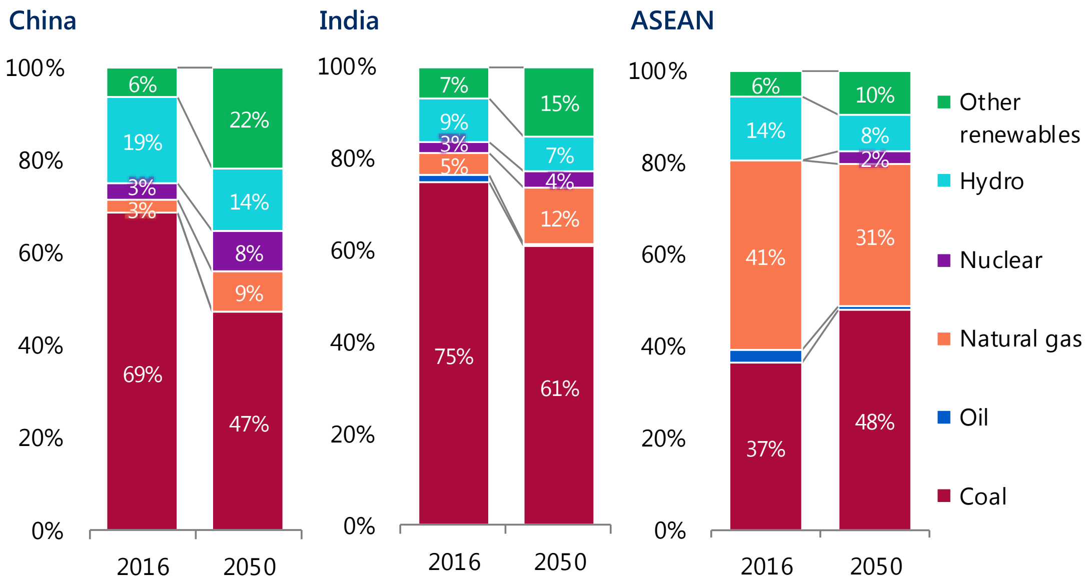


Figure 3-15 | Chinese, Indian and ASEAN power generation mix [Reference Scenario]

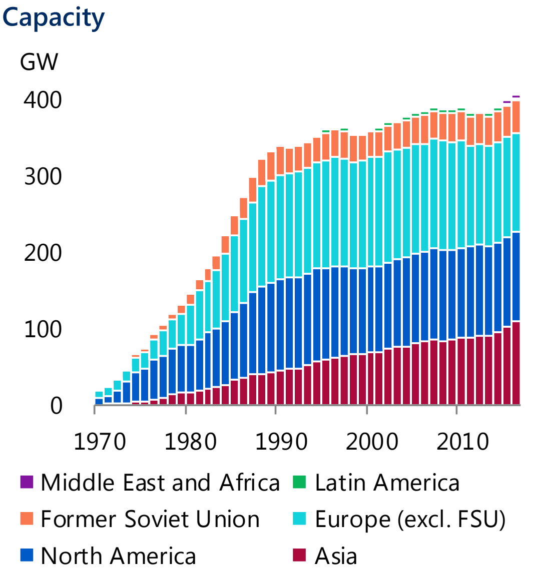


Nuclear

Global installed nuclear power generation capacity rapidly expanded mainly in Europe and the United States in the 1970s and 1980s before slowing down and levelling off in the 1990s. In the second half of the 1990s, the capacity decreased because "poor performance reactors" were decommissioned in Europe and the United States. Since the 2000s, however, the capacity has been steadily rising mainly in Asia, though more slowly than in the 1970s. (Figure 3-16 left side).

After the Fukushima Daiichi Nuclear Power Station Accident, the number of nuclear reactors in operation in the world declined temporarily due to the shutdown of reactors for the implementation of safety measures under new regulatory standards in Japan and the decommissioning of reactors based on a nuclear policy change in Germany and on economic reasons in the United States. Thanks to new nuclear reactor construction mainly in Asia, however, the present number of operating nuclear reactors exceeds the level before the Fukushima accident (Figure 3-16 right side).

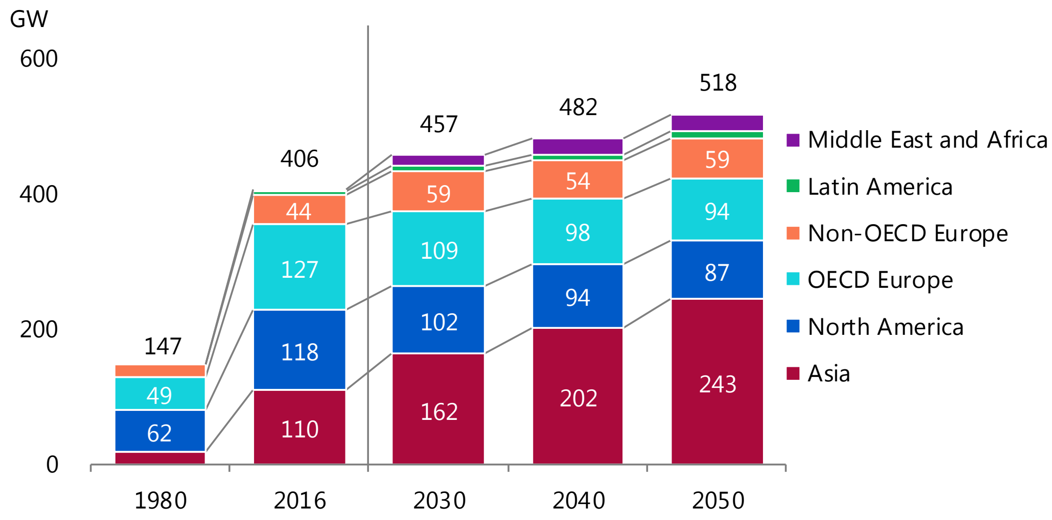
Figure 3-16 | Capacity and number of nuclear reactors



Because of changes in public opinion triggered by the Fukushima accident, growth in construction cost and other factors, it is now difficult to construct new nuclear plants in Japan, Korea, the United States and some European countries. On the other hand, reactors that have been in operation since the 1970s or 1980s are being decommissioned. In the future, therefore, not a small number of countries will reduce nuclear power generation. However, these countries will retain some nuclear power generation capacity to secure stable energy supply, address climate change, and maintain and enhance international competitiveness through their respective nuclear industry promotion. China and some other countries will further promote nuclear power generation.

In the United States, the world's largest nuclear power generating country with 99 reactors, new nuclear plant construction has slowed down in consideration of the increasing economic advantages of natural gas-fired power generation, the development in shale gas production and the expansion of renewable energy power generation. While efforts are pursued to build new reactors and to extend the lifespan of existing reactors to 60 years, the country is shutting down some existing reactors for economic reasons and the U.S. installed capacity for nuclear power generation will decrease gradually through 2050 (Figure 3-17).

Figure 3-17 | Nuclear power generation capacity by region [Reference Scenario]



In France, known as the largest nuclear energy promoter in Europe, the Energy Transition Law was enacted in July 2015 to limit installed nuclear power generation capacity to the present 66 GW (63.2 GW in net power output) and reduce the nuclear share of power generation to 50% by 2025 (from 75% in 2016). In view of a greenhouse gas emission reduction target, however, France has released no plan to close reactors other than the Fessenheim Unit 1 reactor and indicated strategies to revise the target year of 2025. Therefore, France may maintain the present nuclear power generation capacity for the immediate future and reduce the capacity over a longer term. Germany, Switzerland and Belgium have made clear their nuclear phase-out plans in response to the Fukushima accident and will eliminate nuclear generation between 2025 and 2035. Despite some intentions to construct new capacity, other OECD European countries will reduce their respective capacities through 2050 as outdated reactors are being decommissioned. Russia has vowed to proactively use nuclear energy at home and abroad. Its domestic installed nuclear generation capacity will increase from 27 GW to 33 GW in 2030 before levelling off later.

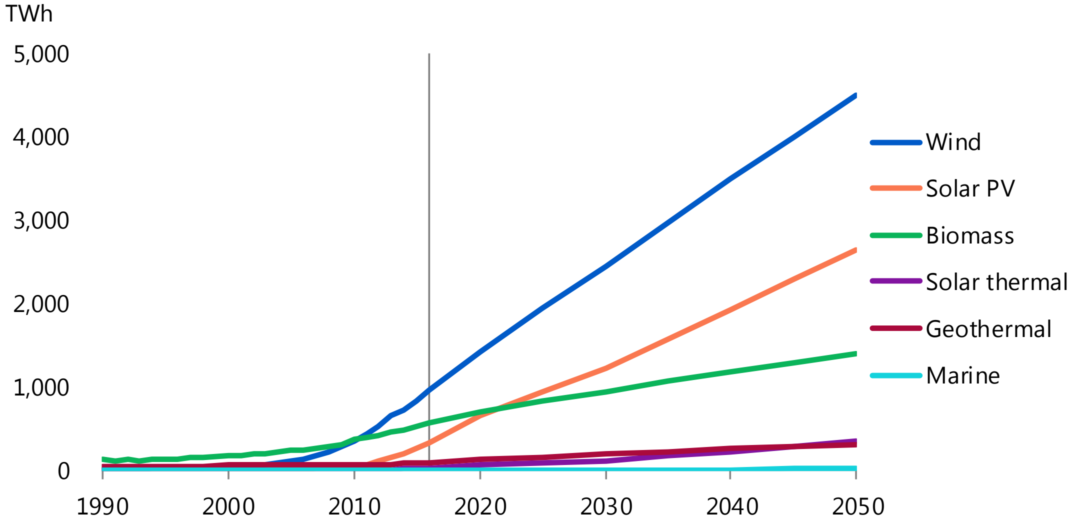
From 2030, Middle Eastern, African, Latin American and other countries, which have so far little exposure to nuclear power generation, will rise as nuclear power generators. The United Arab Emirates, Saudi Arabia and Iran will lead the Middle East and install 22 GW of nuclear power generation capacity by 2050. Latin America, Brazil and Argentina are planning to introduce nuclear power generation to meet domestic electricity demand growth and will construct a few nuclear power plants.

The presence of Asia, including China and India, in nuclear power generation will continuously increase. China will boost its installed nuclear generation capacity from 34 GW in 2016 to 102 GW in 2035, replacing the United States as the largest nuclear power generator in the world. Asian installed nuclear power generation capacity will reach 202 GW in 2040, surpassing the combined OECD Europe and North American capacity of 192 GW.

Renewables

Great expectations are placed on renewable energy including solar and wind energy. Renewable power generation capacity including solar photovoltaic (PV) and wind power generators continued to post smooth growth, while being affected by negative factors such as the reduction of subsidies mainly in developed European countries and crude oil price plunges (Figure 3-18).

Figure 3-18 | Global renewable power generation except hydro [Reference Scenario]



Renewable energy penetration contributes to expanding low-carbon electricity sources, reducing dependence on energy imports and potentially holding down fossil fuel prices. Large-scale renewable energy penetration will depend on cost reduction, improved efficiency and harmonisation of renewables with energy systems through continuous research and development.

Europe, China and North America are major wind power generation markets at present and will drive the wind power generation expansion (Figure 3-19). Meanwhile, India, Brazil, Mexico and other emerging economies will also expand their wind power generation capacity. Installed wind power generation capacity in the world will consequently nearly quintuple from 465 GW in 2016 to 2,254 GW in 2050.

Figure 3-19 | Global wind power generation capacity [Reference Scenario]

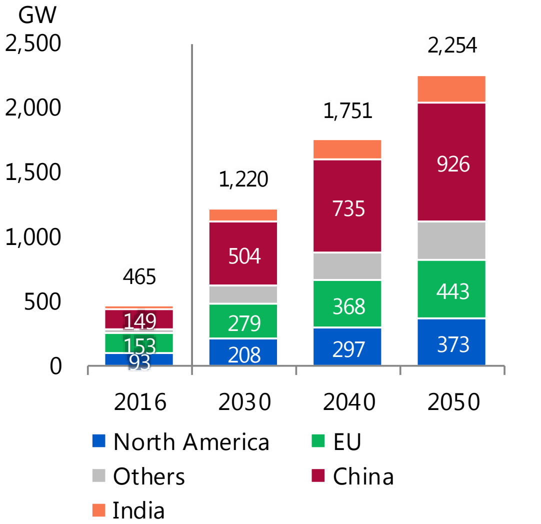
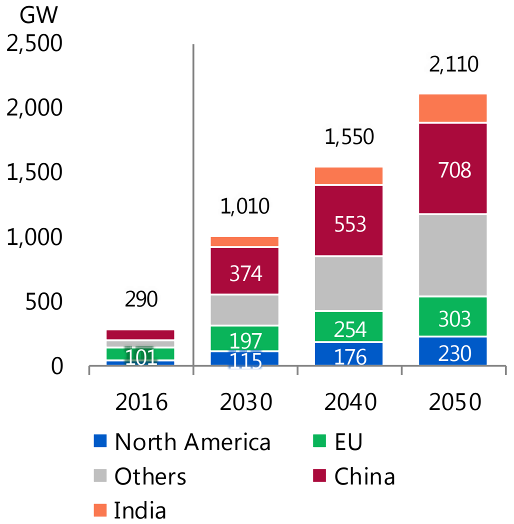


Figure 3-20 | Global solar PV power generation capacity [Reference Scenario]



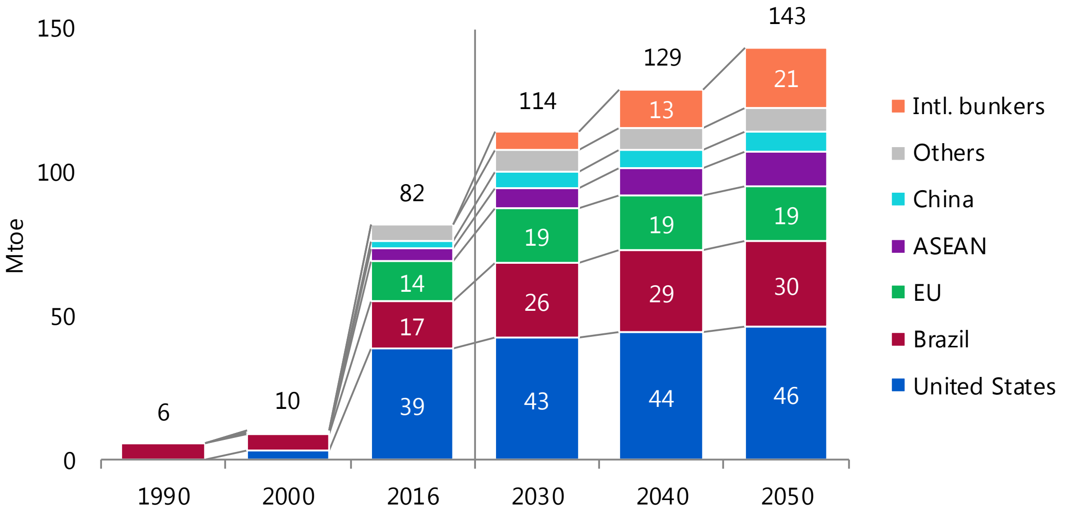
The global solar PV market will continue expanding as China, India, the United States and Japan replace Europe as market leader (Figure 3-20). In solar PV auctions in the United Arab Emirates, Chile and other countries rich with solar radiation, bid prices as low as less than $30/MWh have been recorded, indicating that solar PV generation will grow more competitive. On a global basis, however, solar PV power generation still costs more than traditional power generation technologies. In the Reference Scenario, installed solar PV power generation capacity in the world will expand more than seven-fold from 290 GW in 2016 to 2,110 GW in 2050.

3.5 Biofuels

The penetration of liquid biofuels including bioethanol and biodiesel has made progress as part of measures on climate change, energy security and agriculture promotion. However, biofuel consumption for automobiles is and will remain concentrated in the United States, Brazil and the European Union which accounted for more than 80% of the biofuel consumption in 2016.

Global biofuel consumption will increase from 82 Mtoe in 2016 to 145 Mtoe in 2050 (Figure 3-21). In the United States, biofuel consumption will slightly increase on the penetration of vehicles that can run on fuels with high bioethanol contents. In Brazil, biofuel consumption will robustly expand thanks to the spread of flexible fuel vehicles that can use both ethanol and gasoline. In the European Union, biofuel consumption growth will decelerate from 2030 as demand for liquid fuels slows down and concerns over first-generation biofuels' environmental impact grow. Although ASEAN, China and some other Asian countries will sharply boost biofuel consumption, Asian biofuel consumption will fall short of rivalling the European, U.S. or Brazilin levels. Bio jet fuel, which is used little at present, will begin to be used for international aviation in 2020 or later.

Figure 3-21 | Liquid biofuel consumption [Reference Scenario]



4. Advanced Technologies Scenario

4.1 Major measures

In the Advanced Technologies Scenario, maximum CO_2 emission reduction measures will be implemented with consideration given to their application opportunities and acceptability to society. Each country will strongly implement aggressive energy conservation and decarbonisation policies contributing to securing stable energy supply and to enhancing climate change measures further, while accelerating the development and introduction of innovative technologies globally. Against the backdrop of the introduction of environmental regulations and national targets, the enhancement of technological development and the promotion of international technological cooperation, the demand side will strongly spread energy efficient equipment and the supply side will further promote renewable and nuclear energy (Figure 4-1).

Figure 4-1 | Assumed technologies [Advanced Technologies Scenario]

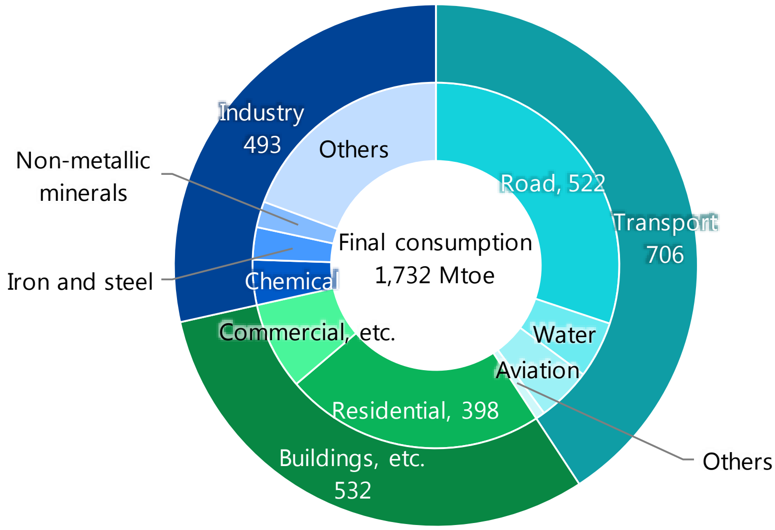
2016 → 2050 (Reference Scenario, 2050)

	Developed countries	Developing countries
Fossil fuel-fired power generation	Developing an initial investment finance scheme. Share of IGCC in new installed plats: 0% → 60% (20%) Installing CCS from 2030 (Countries with carbon storage potential excluding aquifers)	
[Thermal efficiency (stock basis)]	Natural gas: 48.4% → 56.8% (57.0%) Coal: 37.2% → 43.5% (44.3%)	Natural gas: 37.1% → 49.1% (45.9%) Coal: 35.4% → 39.3% (40.6%)
Nuclear power [Capacity]	Maintaining appropriate wholesale prices 2016: 311 GW → 298 (217)	Developing an initial investment finance framework 2016: 96 GW → 550 (302)
Renewables [Capacity]	System cost reduction Power system stabilisation cost reduction Efficient power system operation Wind: 237 GW → 1,091 (718) Solar PV: 165 GW → 909 (573)	System cost reduction Low-cost finance Advancing power systems Wind: 178 GW → 1,912 (1,152) Solar PV: 60 GW → 1,588 (946)
Biofuels [Consumption]	Developing next-generation biofuels Diffusing FFVs further 55 Mtoe → 106 (69)	Biofuel cost reduction Agricultural policy position 27 Mtoe → 81 (54)
Industry	Full diffusion of best available technologies in 2050	
Transportation	Reducing fuel-efficient vehicle costs. Doubling ZEV travel distances.	
[New car fuel efficiency] [ZEV' share of new vehicle sales]	14.5 km/L → 39.3 (28.6) 0.8% → 64% (40%)	12.9 km/L → 30.5 (21.7) 0.6% → 48% (25%)
Buildings	Doubling the pace of improving new electrical appliance efficiency and insulation efficiency (About a 15% improvement from the Reference Scenario in 2050) Electrifying space / water heating and cooking equipment, clean cooking	

Energy efficiency

Final energy consumption in 2050 in the Advanced Technologies Scenario will be 1,732 Mtoe less than in the Reference Scenario. The energy savings amount to 18% of global final energy consumption in 2016. Of the energy savings, the transport sector will account for 706 Mtoe, the buildings sector for 532 Mtoe and the industry sector for 493 Mtoe (Figure 4-2). Because of the huge potential for energy efficiency improvement for vehicles and home appliances, the road sector will be responsible for 522 Mtoe in the transport sector and the residential sector for 398 Mtoe in the buildings sector. Non-OECD will capture more than 50% of energy savings in all final energy consumption sectors, including the industry sector where non-OECD will account for 82% of energy savings. Whether or not non-OECD would realise their potential energy conservation mainly in the industry sector is key to global energy conservation progress.

Figure 4-2 | Energy savings through technology development (compared with Reference Scenario) [Advanced Technologies Scenario, 2050]



By applying presently available high-efficiency technologies for steel, chemical, pulp and paper, and other energy-intensive industries, each of these industries will improve energy intensity in 2050 by some 12% from the Reference Scenario (Table 4-1). Through the energy intensity improvement, the non-OECD industry sector will reduce energy consumption by 404 Mtoe from the Reference Scenario. Asia, where basic materials industries account for a large share of production, will command 58% of the energy savings. OECD countries' transfer of highly efficient technologies to non-OECD countries will make great contributions to improving energy efficiency. OECD countries are expected to implement energy conservation technology research programs and positive cooperation with developing countries.

In the transport sector, fuel efficiency and vehicle fleet mix improvements will make further progress. Hybrid vehicles and ZEVs, including electric, plug-in hybrid and fuel cell vehicles, will expand their share of vehicle sales in 2050 by 20 percentage points from the Reference Scenario. Thanks to the fuel efficiency and vehicle fleet mix improvements, the global average new vehicle fuel efficiency in 2050 will improve by 9.3 km/L from the Reference Scenario to 33.0 km/L (3.0 L/100 km). As ZEVs' share of the vehicle fleet mix in developed countries increases faster, the transport sector will post the largest energy savings among sectors in OECD. International bunkers will make progress in energy conservation through technological innovation and operational improvements. Given their huge potential to switch fuels, natural gas will account for 33% of international marine bunkers and biofuels for 17% of international aviation bunkers.

It is more difficult for energy conservation incentives to work in the buildings sector than in the industry sector that is highly conscious of energy conservation for economic reasons. Therefore, both OECD and non-OECD have great potential to save energy consumption in the buildings sector. The overall global residential and commercial energy efficiency will improve by about 15%. Energy efficiency improvements for space and water heating systems in cold regions and insulation improvements in non-OECD will make great contributions to saving energy. Since kerosene, liquefied petroleum gas, city gas and other fuels are used for water and space heating in various ways depending on national conditions, fuel consumption for water and space heating will be greatly reduced. Particularly, traditional biomass consumption including inefficient fuel wood and manure will be reduced most through the expansion of electrification and the diffusion of modern cooking equipment in such areas. Electricity consumption will decline substantially as energy conservation in wide-ranging fields such as cooling, powering and lighting more than offsets the effect of the electrification of appliances.

Table 4-1 | Energy indicators

		2016	2050 Reference	2050 Advanced Technologies
Industry	Intensities (2016 = 100)			
	Iron and steel	100	72.8	63.3
	Non-metallic minerals	100	80.2	70.6
	Chemical	100	76.0	66.8
	Paper and pulp	100	80.6	71.9
	Other industries	100	68.4	59.8
Transport	New passenger vehicle fuel efficiency (km/L)	13.6	23.7	33.0
	ZEVs' share of vehicle sales	0.6%	26%	46%
	Natural gas's share in intl. marine bunkers	0.0%	16%	33%
	Biofuel's share of intl. aviation bunkers	0.0%	5.5%	17%
Buildings	Overall energy efficiency (2016 = 100)			
	Residential	100	61.9	51.2
	Commercial	100	46.5	39.8
	Electrification rate			
	Residential	24%	35%	37%
	Commercial	52%	63%	65%

Note: Energy intensity is energy consumption per production and overall energy efficiency is energy consumption per energy service.

Renewables

In the Advanced Technologies Scenario, renewables (including hydro) will increase their share of primary energy consumption from 14% in 2016 to 22% in 2050, 5 percentage points higher than in the Reference Scenario. Driving the renewable energy share expansion will be wind and solar photovoltaics. The share for wind, solar PV, concentrated solar and marine power generation will rise from 1.1% in 2016 to 6.9% in 2050.

The spread of wind power generation will accelerate mainly in emerging and developing countries and the United States as onshore wind power plant costs are further reduced and electricity transmission infrastructure is developed. Offshore wind power generation will expand mainly in Europe as construction, operation and management, and grid connection costs are reduced (Figure 4-3). Global installed wind power generation capacity in 2050 in the Advanced Technologies Scenario will reach 3,351 GW, nearly 1.5 times as much as in the Reference Scenario.

Solar PV power generation will spread further in emerging and developing countries thanks to system cost cuts (Figure 4-4). Solar PV power generation will significantly grow in the Sun Belt (rich with sunlight resources) including China, India, the Middle East, North Africa and Latin America. In developed countries, storage cell price cuts will accelerate the spread of solar PV generation. Global installed solar PV generation capacity in 2050 will be 2,992 GW, 1.4 times as large as in the Reference Scenario.

Figure 4-3 | Global installed wind power generation capacity [Advanced Technologies Scenario]

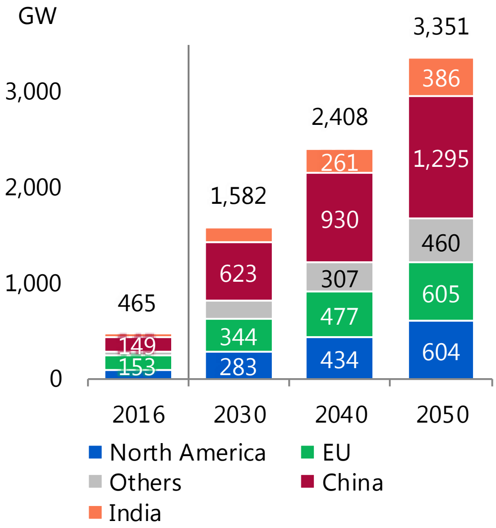
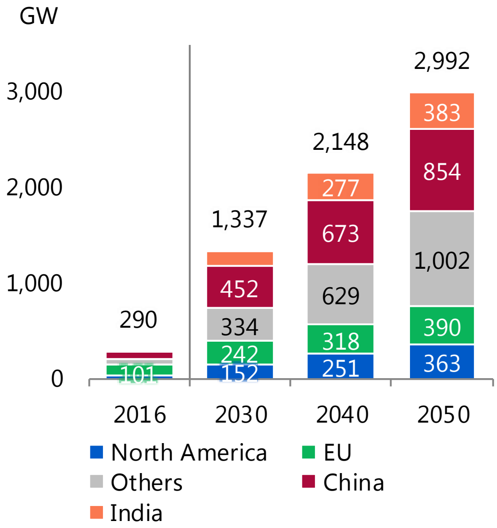


Figure 4-4 | Global installed solar PV power generation capacity [Advanced Technologies Scenario]



Factors for accelerating the spread of wind, solar PV and other intermittent power sources include not only the reduction of construction and system costs but also the reduction of environmental load and the improvement of investors' and consumers' environmental consciousness. Also playing major roles in spreading these intermittent power sources will be power generation prediction technologies, output control, storage technologies, transmission and distribution network expansion and the enhancement of grid stabilisation through smart grid systems combining these and information technologies.

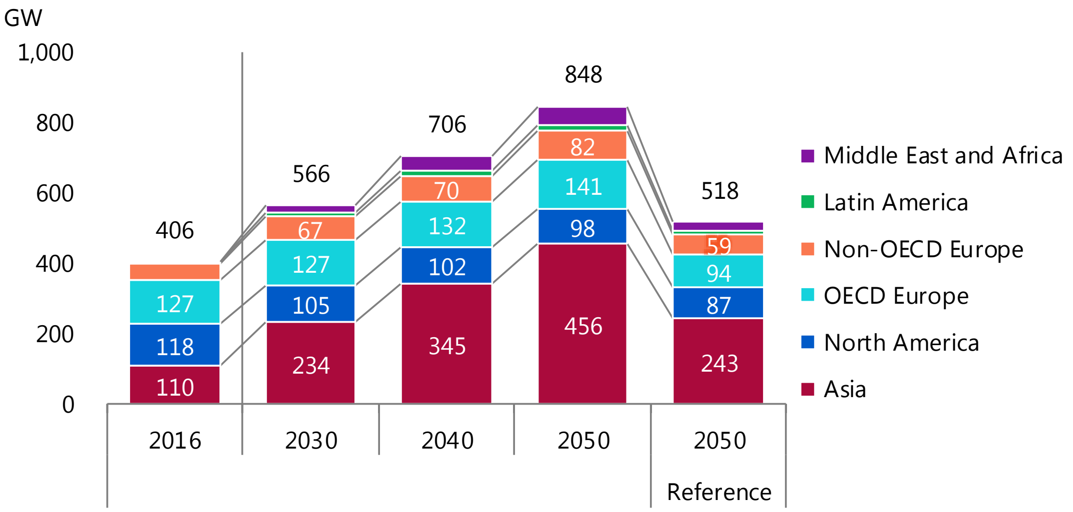
Nuclear

Great expectations are placed on the introduction of nuclear power generation as a decarbonisation measure. Emerging economies are considering introducing nuclear power generation to meet the rapid growth in their electricity demand and promote decarbonisation. Among countries that have traditionally and proactively promoted nuclear power generation, the United States and France will reduce their nuclear power generation capacity from 2016.

The United Kingdom and Russia will build new nuclear power plants to increase their capacity. Countries such as Belgium clarified their nuclear phase-out policy in response to the Fukushima accident but could change that policy to put off their nuclear power plant shutdown and replace decommissioned capacity to promote decarbonisation and maintain their industrial competitiveness.

In the Advanced Technologies Scenario, installed nuclear power generation capacity will increase from 406 GW in 2016 to 848 GW in 2050 (Figure 4-5), 1.6 times as much as 518 GW in the Reference Scenario.

Figure 4-5 | Installed nuclear power generation capacity [Advanced Technologies Scenario]



North America will reduce installed nuclear power generation capacity to 98 GW in 2050 due primarily to a decrease in the United States. Factors behind the U.S. capacity decrease include the shutdown of some plants with deteriorated efficiency, a recent slowdown in electricity demand, and cheap natural gas and renewable energy prices. Given that the U.S. federal government and some state governments are reassessing the reliability of nuclear energy supply and considering incentives for nuclear research and development as well as nuclear power generation, however, nuclear could be expected to play a greater role than in the Reference Scenario. U.S. installed nuclear power generation capacity in the Advanced Technologies Scenario will be 87 GW in 2050.

OECD Europe will decommission outdated reactors and construct replacements, eventually increasing installed nuclear power generation capacity in 2050 to 141 GW from 127 GW in 2016. In the United Kingdom, for example, installed capacity will increase to 16 GW in 2050 as new plants are built, with some outdated reactors being decommissioned.

Russia will accelerate the construction of new nuclear power plants, sharply expanding installed nuclear power generation capacity from 27 GW in 2015 to 34 GW in 2040. While Russian capacity will level off later, East European countries will steadily implement their nuclear power plant construction.

In Asia, China and India will drive new nuclear power plant construction. Southeast Asian countries will also make progress in nuclear power plant construction. Asia's installed nuclear power generation capacity will surpass the combined capacity of OECD Europe and North America (at 232 GW) in 2030 and reach 456 GW in 2050. China will boost its capacity beyond the U.S. level of 94 GW and replace the United States as the world's largest nuclear power generator in 2030 and expand its capacity further to 250 GW in 2050. India, though with installed nuclear power generation capacity limited to 6 GW in 2016, has put forward a proactive nuclear power generation capacity expansion target and will boost its capacity to 37 GW in 2030 and to 90 GW in 2050.

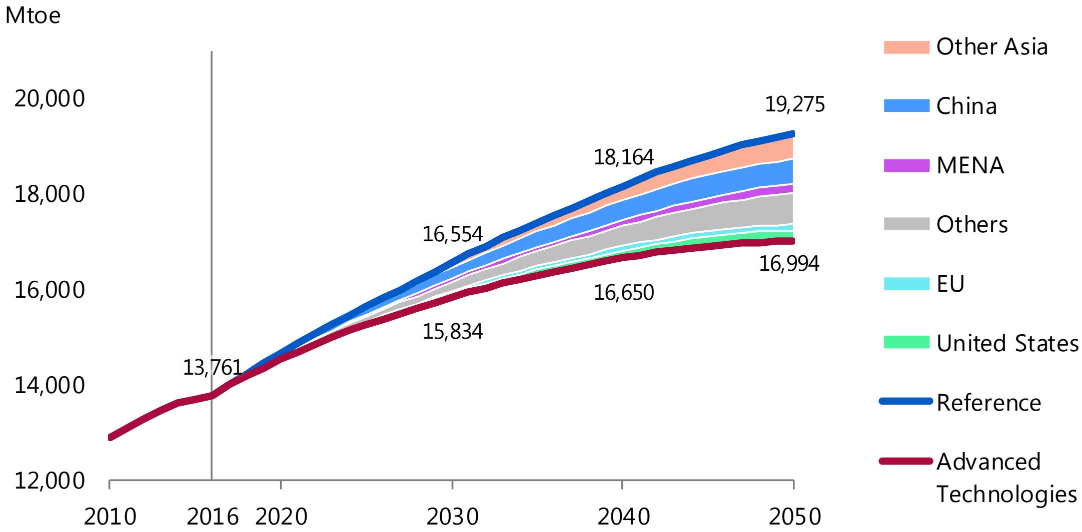
The Middle East, Africa and Latin America, known as emerging nuclear energy markets, will launch the operation of new reactors around 2025 and steadily expand installed nuclear power generation capacity thereafter. In the Middle East where mainly the United Arab Emirates and Saudi Arabia are planning to build nuclear power plants, installed nuclear power generation capacity will reach 19 GW in 2030 and 37 GW in 2050.

4.2 Energy supply and demand

Primary energy consumption

The strong implementation of the abovementioned energy conservation and climate change measures will substantially reduce primary energy consumption (Figure 4-6). Primary energy consumption in 2050 in the Advanced Technologies Scenario will total 16,994 Mtoe, down 2,281 Mtoe from the Reference Scenario. The gap corresponds to some 17% of global primary energy consumption in 2016. Accumulated energy savings through 2050 will total about 35 Gtoe, 2.6 times as much as annual global primary energy consumption.

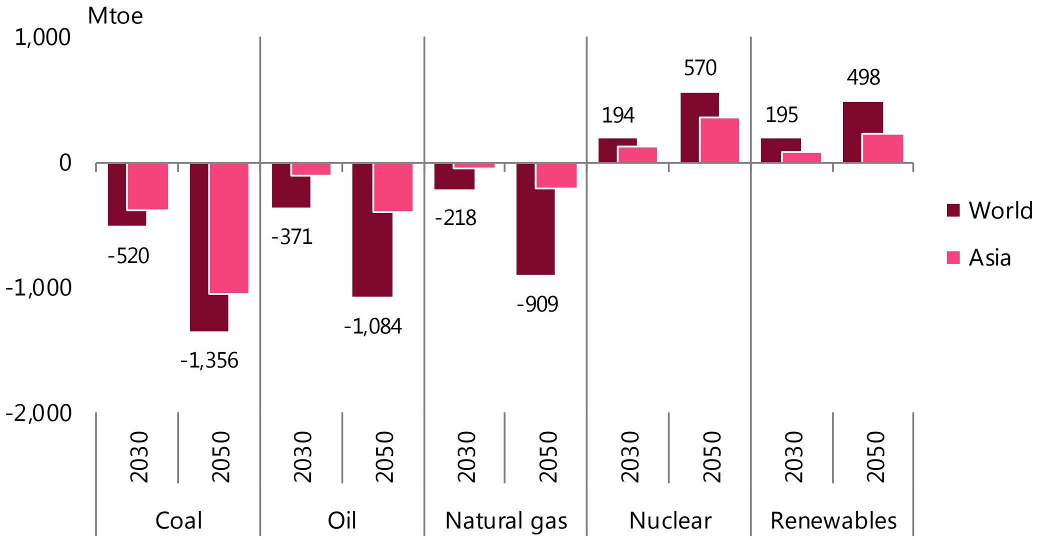
Figure 4-6 | Global primary energy consumption and savings by region



In transiting to the Advanced Technologies Scenario, non-OECD and Asian countries, projected to expand energy demand while offering great energy conservation potential, will play a great role. Non-OECD will account for 74% of global energy savings in 2050 and Asia for 47%. Non-OECD and Asian energy consumption holds the key to reforming the broadly defined global energy system, including consumption and production patterns for energy sources required by the world and energy consumption's influence on the global environment.

Among energy sources, fossil fuels will post great primary energy consumption savings (Figure 4-7). Of the 2,281-Mtoe decline in primary energy consumption from the Reference Scenario in 2050, coal will account for 1,356 Mtoe, oil for 1,084 Mtoe and natural gas for 909 Mtoe. Meanwhile, nuclear and renewable energy will accelerate their spread. Nuclear consumption in the Advanced Technologies Scenario will be 570 Mtoe (including 361 Mtoe in Asia) more than in the Reference Scenario. Renewable energy consumption excluding hydro will be 498 Mtoe (including 223 Mtoe in Asia) more. As a result, fossil fuels' share of primary energy consumption in the Advanced Technologies Scenario will fall from 81% in 2016 to 69% in 2050.

Figure 4-7 | Global primary energy consumption changes from Reference Scenario [Advanced Technologies Scenario]

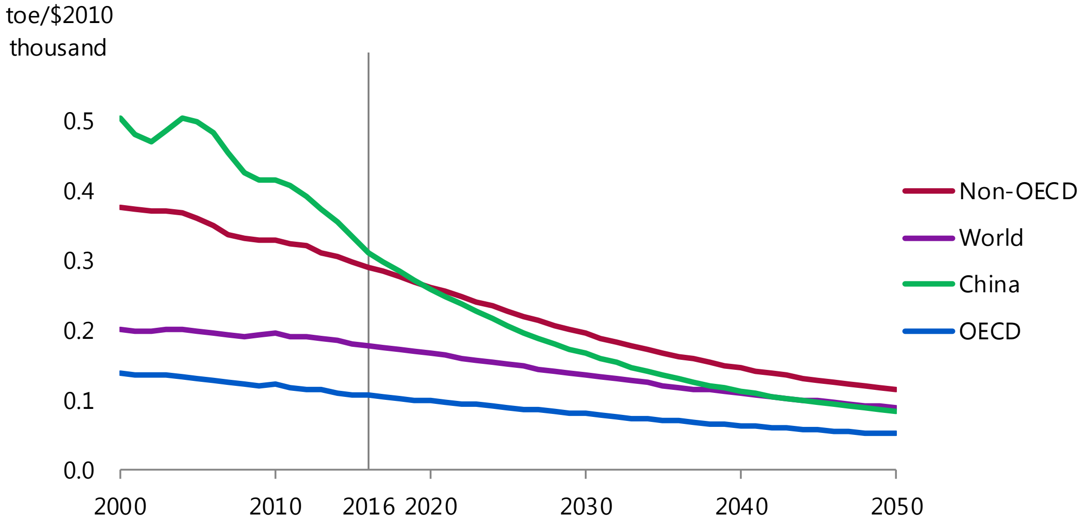


Asia, including China and India, will account for 49% of the fossil fuel consumption savings and will capture as much as 78% of the coal consumption savings. Asia will also account for 63% of nuclear consumption growth, while its share of the growth in renewable energy consumption, other than hydro will be limited to 45%.

The world's GDP energy intensity, or primary energy consumption per unit of GDP, an indicator of macro energy efficiency, will plunge by 50% from 2016 to 2050 (Figure 4-8). OECD will post a moderate decline of 52% against 61% for non-OECD, which have greater potential to improve energy efficiency and will narrow the gap with OECD. China's GDP energy intensity, which has been rapidly declining due to industrial structure changes, will continue declining and slip below the non-OECD average around 2020, and catch up with the global average by the mid-2040s. Asia's GDP energy intensity will drop by 59% by 2050.

Asia will play a very important role in realising the global energy system depicted in the Advanced Technologies Scenario. Asia must eliminate energy conservation barriers including the lack of fundraising capacity and consciousness that blocks the penetration of technologies. The region must spread energy-saving equipment by offering them at reasonable prices to low-income people and provide energy-saving technologies that take into consideration differences between urban and suburban lifestyles. Each country must implement education programs to enhance energy conservation consciousness on a nationwide basis. Bilateral cooperation schemes, as well as multilateral frameworks such as the ASEAN+3 and Asia Pacific Economic Cooperation forums, will help promote such education.

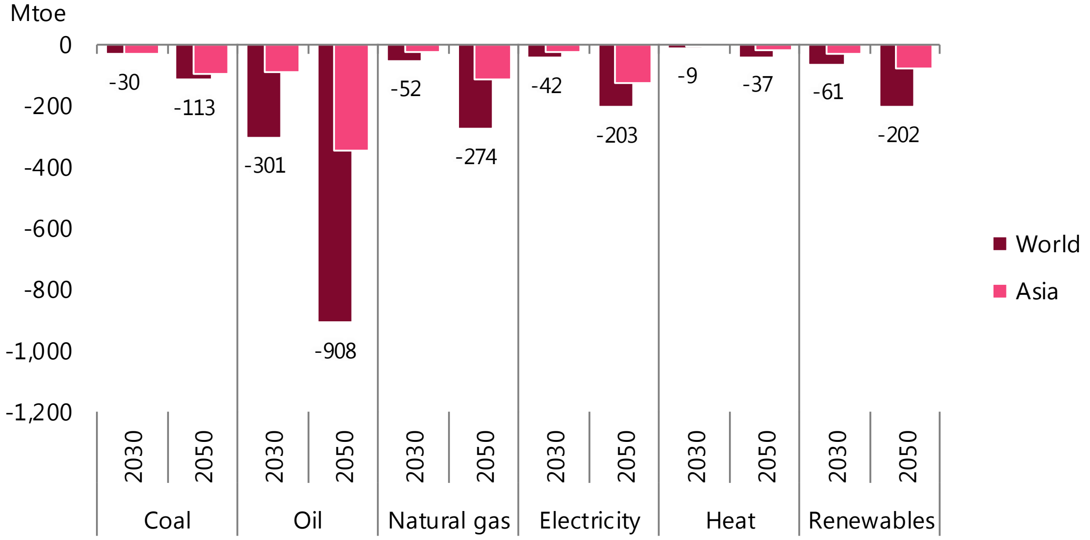
Figure 4-8 | GDP energy intensity [Advanced Technologies Scenario]



Final energy consumption

Final energy consumption in 2050 in the Advanced Technologies Scenario will be 1,732 Mtoe less than in the Reference Scenario. Of the energy savings, oil will account for 908 Mtoe or 52% (Figure 4-9).

Figure 4-9 | Final energy consumption changes from Reference Scenario [Advanced Technologies Scenario]



Energy conservation progress, mainly in the transport sector, will make great contributions to oil consumption savings. In the Advanced Technologies Scenario, oil's share of energy consumption in the road sector will decline from 94% in 2016 to 77% in 2050 as ZEVs spread (Figure 4-10). From the Reference Scenario, electricity will post the largest increase in the sector's energy consumption (Figure 4-11).

Figure 4-10 | Global road sector energy consumption mix

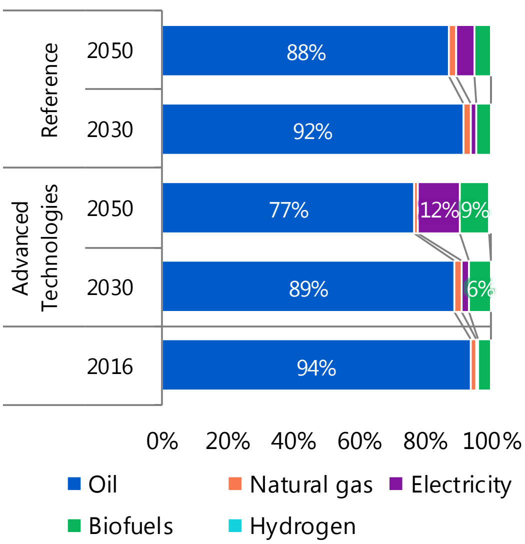
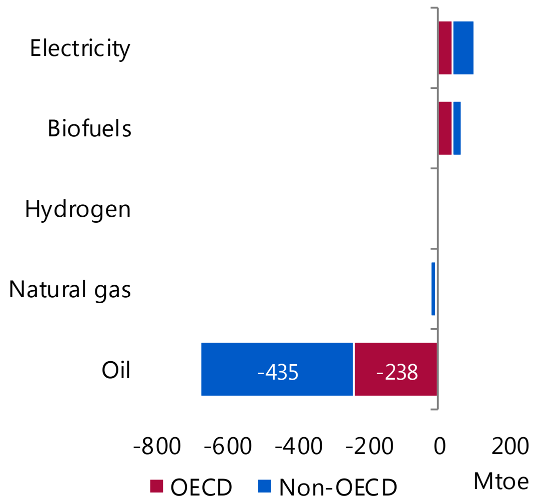


Figure 4-11 | Global road sector energy consumption changes from Reference Scenario [Advanced Technologies Scenario, 2050]

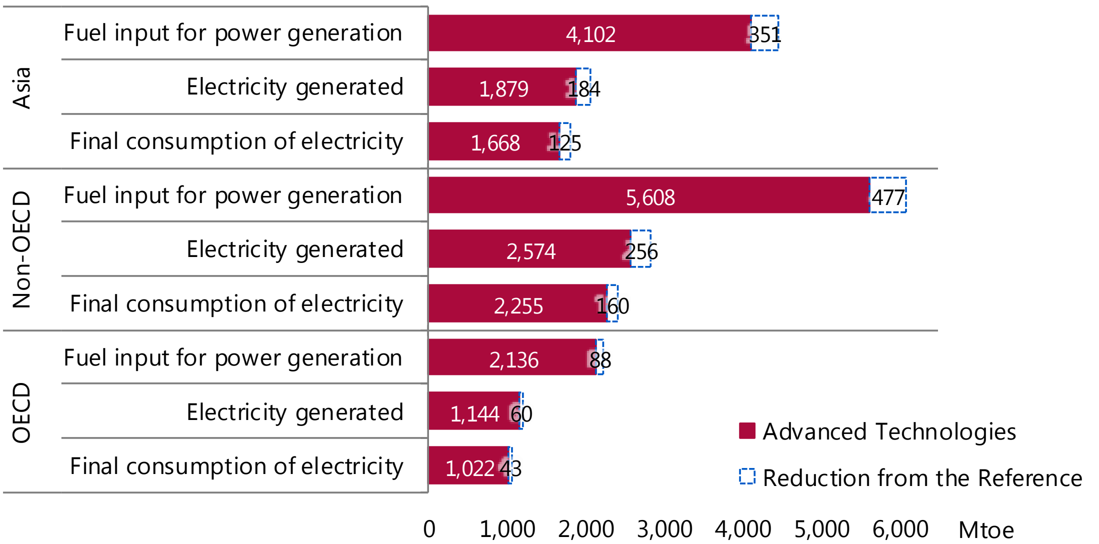


Final electricity consumption in 2050 in the Advanced Technologies Scenario will be reduced by 203 Mtoe from the Reference Scenario, lowering required power generation by 316 Mtoe. The electricity savings will be coupled with power generation efficiency improvement to save primary energy consumption by 565 Mtoe (Figure 4-12). The savings are equivalent to 25% of total primary energy consumption savings. Making great contributions to the savings will be Asia. Through the introduction of new power generation equipment and the replacement of outdated equipment accompanying electricity demand growth, Asian emerging economies' power generation efficiency will improve substantially to almost the same levels as in developed countries by 2050.

Developed countries should cooperate with emerging economies in improving power generation efficiency globally. Emerging economies frequently fail to consider environmental conservation, giving top priority to high economic growth. For example, they hesitate to address air pollution from fossil fuel-fired power generation as efforts to solve air pollution problems are likely to reduce economic efficiency. Therefore, it will become more important that developed countries take advantage of their past overcoming of environmental problems to cooperate with emerging economies.

In addition to technologies for improving power generation efficiency, those for limiting electricity consumption itself are important. A particularly key challenge in developed countries as well as others is how to restrict electricity consumption in the buildings sector that increases consumption in line with living standard improvements. Home energy management systems (HEMS) including smart meters, building energy management systems (BEMS) and other technologies to control energy consumption are expected to spread in developed countries and be transferred to emerging economies.

Figure 4-12 | Primary energy consumption reduction through final electricity consumption savings [Advanced Technologies Scenario in 2050]

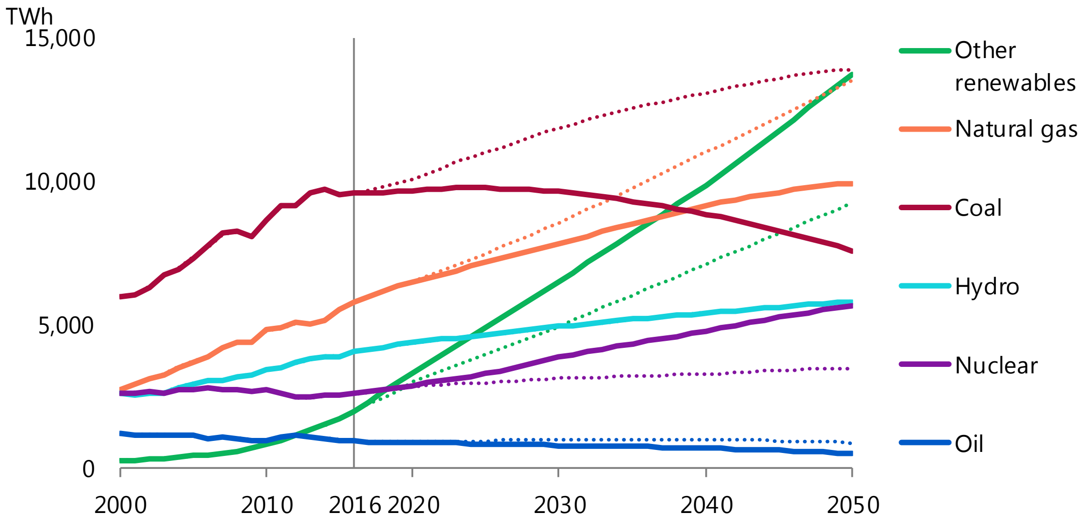


Asia will account for 84% of global final coal consumption reduction totalling 113 Mtoe in 2050. In this respect, steelmakers' energy conservation will be important in India and other countries where crude steel production will expand rapidly. Japan's energy consumption per unit of steel production is at one of the lowest levels in the world, standing at about one-third of India's. If highly efficient technologies are transferred from Japan and other developed countries to India and other Asian emerging economies, relevant sectors' energy consumption savings will become more feasible. Developed countries will contribute to energy savings not only in energy-saving equipment and other hardware but also in software including equipment operations.

Power generation mix

In the Advanced Technologies Scenario, final electricity consumption savings will work to cut power generation by about 3,670 TWh, equivalent to power generation in OECD Europe in 2016. The integrated gasification combined cycle (IGCC) for coal-fired power generation and the development of technology for mixing coal with biomass will contribute to cutting coal consumption for power generation substantially. In contrast to coal, non-hydro renewables including solar PV, wind and biomass will become the largest power source and nuclear power generation will increase its presence (Figure 4-13).

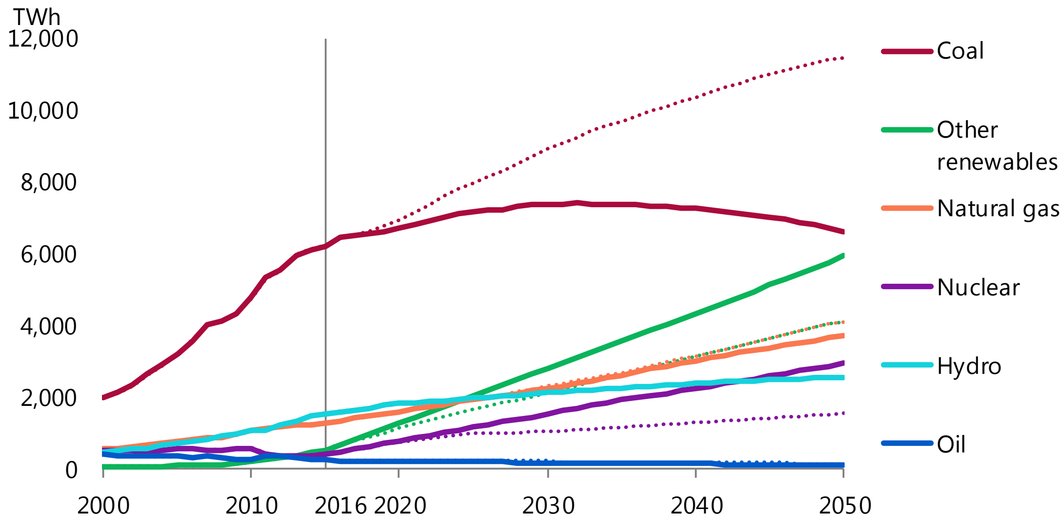
Figure 4-13 | Global power generation mix [Advanced Technologies Scenario]



Note: Dashed lines represent the Reference Scenario.

In Asia as well, coal-fired power generation will be reduced substantially. Nevertheless, coal's share of power generation in 2050 in Asia will still be larger than in any other region (Figure 4-14). As China and other Asian countries have promoted the introduction of renewable energy technology, it is important for them to reduce coal consumption while continuing to expand renewable energy consumption.

Figure 4-14 | Global power generation mix [Advanced Technologies Scenario]



Note: Dashed lines represent the Reference Scenario.

Crude oil production

In the Advanced Technologies Scenario, oil consumption will be 7% less than in the Reference Scenario in 2030 and 19% less in 2050 due to progress in energy conservation and fuel switching. As oil consumption growth decelerates dramatically to zero or slightly negative around 2030, crude oil production will decrease (Table 4-2).

Table 4-2 | Crude oil production [Advanced Technologies Scenario]

(Mb/d)

	2016	2030	2040	2050	2016-2050	
					Changes	CAGR
Crude oil production	92.0	95.5	95.0	92.4	0.4	0.0%
OPEC	39.9	40.8	43.6	44.4	4.6	0.3%
Middle East	174.8	176.2	175.7	171.1	-3.7	-0.1%
Others	53.1	52.6	53.2	52.1	-1.0	-0.1%
Non-OPEC	52.2	54.7	51.4	48.0	-4.2	-0.2%
North America	16.8	21.6	19.4	16.7	-0.1	0.0%
Latin America	6.9	7.8	8.8	9.4	2.5	0.9%
Europe / Eurasia	17.7	15.7	14.1	13.1	-4.6	-0.9%
Middle East	1.3	1.4	1.4	1.4	0.1	0.3%
Africa	1.3	1.4	1.4	1.4	0.1	0.2%
Asia and Oceania	8.0	6.8	6.2	5.9	-2.2	-0.9%
Processing gains	2.3	2.6	2.7	2.8	0.5	0.6%
Biofuels	2.2	4.2	5.6	6.7	4.5	3.3%
GTL and CTL	0.3	0.9	1.0	1.1	0.8	4.0%
Liquid fuel supply	96.9	103.2	104.4	103.0	6.1	0.2%

As oil producing countries intensify competition with each other, however, relatively cost competitive OPEC's share of crude oil production will be higher than in the Reference Scenario.

In North America, Africa and Latin America that are less cost competitive, as well as Europe and Eurasia including Russia that provides oil mainly to Europe featuring falling consumption, oil production will be far less than in the Reference Scenario. In Asian and other net oil importing countries, production falls will be limited from the viewpoint of supply security, allowing oil self-sufficiency rates to be higher than in the Reference Scenario.

Natural gas supply

As progress in energy utilisation technologies, including energy conservation technologies, suppresses natural gas consumption in the Advanced Technologies Scenario, natural gas production will be 11% less than in the Reference Scenario in 2040 and 18% less in 2050 (Table 4-3). However, gaps with the Reference Scenario for natural gas are smaller than for oil or coal.

Table 4-3 | Natural gas production [Advanced Technologies Scenario]

(Bcm)

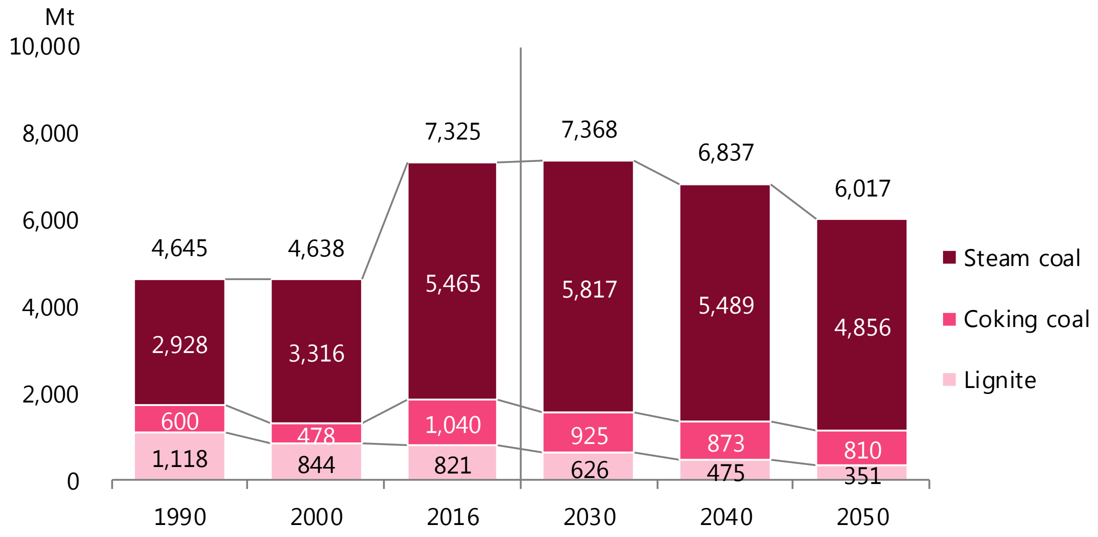
	2016	2030	2040	2050	2016-2050	
					Changes	CAGR
World	3,502	4,333	4,762	4,912	1,410	1.0%
North America	901	1,180	1,244	1,158	257	0.7%
Latin America	199	247	294	338	139	1.6%
OECD Europe	245	169	131	64	-181	-3.9%
Non-OECD Europe / Central Asia	790	908	954	1,001	211	0.7%
Russia	599	673	741	783	184	0.8%
Middle East	610	744	824	972	362	1.4%
Africa	211	324	428	436	225	2.2%
Asia	466	591	705	756	291	1.4%
China	133	237	335	373	240	3.1%
India	30	58	81	85	55	3.1%
ASEAN	213	211	215	228	15	0.2%
Oceania	81	170	182	187	106	2.5%

A wide production gap between the Reference and Advanced Technologies Scenarios will be seen in OECD Europe where natural gas development costs are relatively higher. The region's natural gas production in 2050 in the Advanced Technologies Scenario will be some 40% less than in the Reference Scenario. North American production will peak and turn down around 2040. The Middle East and non-OECD Europe will expand natural gas production steadily, though more slowly than in the Reference Scenario.

Coal supply

In the Advanced Technologies Scenario, coal consumption will decline due to improvement in coal utilisation efficiency and a fall in coal's share of the power generation mix. Consequently, coal production will decrease from 7,325 Mt in 2016 to 6,017 Mt in 2050 (Figure 4-15). Steam coal production will decline from 5,465 Mt in 2016 to 4,856 Mt in 2050, coking coal production from 1,040 Mt to 810 Mt and lignite production from 821 Mt to 351 Mt. From the Reference Scenario, coal production in 2050 will decrease by 3,083 Mt including 2,577 Mt for steam coal, 203 Mt for coking coal and 302 Mt for lignite.

Figure 4-15 | Coal production [Advanced Technology Scenario]



Coal production will decline substantially in North America, OECD Europe and China where consumption will plunge (Table 4-4). Meanwhile, coal production will increase in line with demand growth in India and Indonesia. As international coal trade decreases due to a global consumption drop, coal exporting countries' production will level off or decline depending on local conditions.

Table 4-4 | Coal production [Advanced Technologies Scenario]

Steam coal production (Mt)

	2016	2030	2040	2050	2016-2050 Changes	2016-2050 CAGR
World	5,465	5,817	5,489	4,856	-609	-0.3%
North America	571	390	243	118	-453	-4.5%
United States	544	387	240	115	-429	-4.5%
Latin America	101	112	116	114	13	0.4%
Colombia	86	98	102	101	15	0.5%
OECD Europe	72	54	36	23	-49	-3.3%
Non-OECD Europe / Central Asia	324	304	301	279	-45	-0.4%
Russia	209	209	210	200	-9	-0.1%
Middle East	0	0	0	0	0	1.1%
Africa	258	285	286	267	9	0.1%
South Africa	252	269	263	239	-12	-0.1%
Asia	3,889	4,403	4,217	3,780	-109	-0.1%
China	2,721	2,761	2,444	1,907	-814	-1.0%
India	609	998	1,114	1,207	598	2.0%
Indonesia	460	541	552	552	92	0.5%
Oceania	251	269	288	275	25	0.3%
Australia	250	268	287	275	25	0.3%

Coking coal (Mt)

	2016	2030	2040	2050	2016-2050	
					Changes	CAGR
World	1,040	925	873	810	-230	-0.8%
North America	75	64	60	52	-23	-1.2%
United States	50	42	39	33	-17	-1.3%
Latin America	9	9	9	9	1	0.2%
Colombia	4	5	5	5	1	0.4%
OECD Europe	20	14	12	10	-9	-1.9%
Non-OECD Europe / Central Asia	110	100	95	89	-21	-0.6%
Russia	84	73	68	62	-21	-0.8%
Middle East	1	1	1	1	0	0.0%
Africa	8	10	10	10	2	1.0%
Mozambique	4	6	7	7	3	1.2%
Asia	627	559	523	487	-140	-1.0%
China	547	435	376	325	-222	-2.0%
India	57	105	128	145	88	3.1%
Mongolia	20	15	13	11	-9	-1.9%
Oceania	190	167	163	152	-38	-0.4%
Australia	189	166	161	151	-38	-0.5%

4.3 CO_2 / GHG emissions

Paris Agreement and GHG emission reduction targets

The 21st Session of the Conference of Parties to the United Nations Framework Convention on Climate Change (COP21) in December 2015 adopted the Paris Agreement, a new international framework to reduce greenhouse gas (GHG) emissions from 2020.

The Ad Hoc Working Group on the Paris Agreement is considering (1) a guidance for Nationally Determined Contributions (NDCs) (including emission reduction targets) to be communicated every five years and a global stocktake to review progress toward the achievement of long-term targets every five years, (2) procedures and guidelines for a framework to secure the transparency of mitigation actions and support regarding the achievement of targets, as well as a mechanism for implementing and complying with the agreement, (3) a guidance for communicating adaptation needs and (4) how to discuss funding and other matters. Preparations for implementing the Paris Agreement are planned to be completed by the COP24 scheduled to take place in Poland's Katowice in December 2018.

Table 4-5 | Overview of the Paris Agreement

Item	Contents
Mitigation (reduction) Ex ante process for setting targets	The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) shall periodically take stock of the implementation of this agreement to assess the collective progress towards achieving the purpose of this agreement and its long-term goals (referred to as the "global stocktake"). Each party shall communicate a nationally determined contribution (reduction targets, etc.) every five years and be informed by the outcomes of the global stocktake. All Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies. COP decided: To convene a "facilitative dialogue" among Parties in 2018 to take stock of the collective efforts of Parties in relation to progress towards the long-term goal (as a precursor of the global stocktake); To invite the Intergovernmental Panel on Climate Change (IPCC) to provide a special report in 2018 on the impact of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways.
Mitigation (reduction) Ex post review of target achievements	Information submitted by each Party on emissions and support shall undergo a technical expert review. Each party shall participate in a facilitative, multilateral consideration of progress with respect to efforts on finance, and its respective implementation and achievement of its nationally determined contribution. A mechanism to facilitate implementation of and promote compliance with the provision of this Agreement is established.
Adaptation	Parties establish the global goal on adaptation of including reducing of vulnerability to climate change The adaptation efforts of developing country Parties shall be recognised. Each party should, appropriate, submit and update periodically an adaptation communication.
Finance	Developed country Parties shall biennially communicate indicative quantitative and qualitative information on financial resources and the mobilization of climate finance, as applicable, including, as available, projected levels of public financial resource to be provided to developing country Parties. COP decided: Prior to 2025 CMA shall set a new collective quantified goal from a floor of USD100 billion per year by 2020.

Major parties to the Paris Agreement are required to update their NDCs every five years (see Table 4-6 for present NDCs). Updated NDCs will have to be tougher than previous ones. In this way, progress toward long-term targets will be assessed every five years in the so-called global stocktake. Assessment results will have to be considered when NDCs are communicated every five years.

Table 4-6 | Major parties' NDCs

	Target type	Reduction level (%)	Reference point	Target year	Target sector or gas
China	GDP emission intensity reduction from the reference year	60-65	2005	2030	CO_2 emissions
United States	Emission reduction from the reference year	26-28	2005	2025	GHG emissions*
European Union	Emission reduction from the reference year	40	1990	2030	GHG emissions
Russia	Emission reduction from the reference year	25-30	1990	2030	GHG emissions
India	GDP emission intensity reduction from the reference year	33-35	2005	2030	GHG emissions
Japan	Emission reduction from the reference year	26	2013	2030	GHG emissions
Brazil	Emission reduction from the reference year	37 (43 in 2030)	2005	2025	GHG emissions
Indonesia	Emission reduction from BAU	29	BAU	2030	GHG emissions

Note: *Emissions in the reference year including land use, land use change and forestry.
Although the United States notified the United Nations of its withdrawal from the Paris Agreement on August 4, 2017, its NDCs are given here because the withdrawal is set to take effect on November 4, 2020, at the earliest.

Before the 2023 global stocktake, the Paris Agreement parties are convening a Talanoa or facilitative dialogue in 2018 to assess their efforts for progress toward the achievement of their long-term emission reduction targets under the agreement. In response to the assessment, they will notify the United Nations of their 2030 targets in early 2020 anew. To steadily realise emission reduction targets under the agreement and lead to further emission cuts, the parties will have to objectively assess their targets and make efforts assumed in the Advanced Technologies Scenario. In addition, technology transfers and financial assistance to developing countries as well as technological innovation will have to be promoted to back up emission reduction measures.

Advanced Technologies Scenario

In the Advanced Technologies Scenario in which energy conservation and low-carbon technologies will be further advanced, global energy-related CO_2 emissions will peak around 2025 and slowly decline (Figure 4-16) before reaching 28.7 Gt in 2050, down 11.2% from 2016. A CO_2 emission decline of 13.2 Gt or 31% from the Reference Scenario will surpass present

OECD emissions at 11.5 Gt. A cumulative decline of 206 Gt through 2050 will be equivalent to 6.4 years' worth of present global annual emissions.

Non-OECD will account for about three quarters of the emission decline from the Reference Scenario in 2050, indicating developing countries' great potential to reduce emissions. A decline in China, the largest CO_2 emitter in the world, will come to 3.1 Gt, almost equivalent to the present emission level of 3.2 Gt for the European Union (Figure 4-17). A little more than 60% of the decline will be attributable to a coal consumption cut in the power generation sector. In China that heavily depends on coal-fired power generation (that accounts for 70% of present total Chinese power generation and will capture nearly 50% even in 2050 in the Reference Scenario), electricity demand reduction, power generation efficiency improvement and switching to non-fossil power sources will become great factors to cut CO_2 emissions. India, which will replace the United States as the second largest CO_2 emitter in the world by 2035, will reduce emissions by 2.1 Gt, almost equivalent to its present emissions. In India that heavily depends on coal-fired power generation as does China, nearly 60% of the emission reduction will be attributable to a coal consumption cut in the power generation sector. The reduction of CO_2 emissions in Asian and other developing countries will be indispensable as an effective climate change measure. In this sense, developing countries' emission reduction efforts and developed countries' relevant technology transfers to and institution-building support for developing countries to spread low-carbon technologies will be very significant.

Figure 4-16 | Global energy-related CO_2 emissions

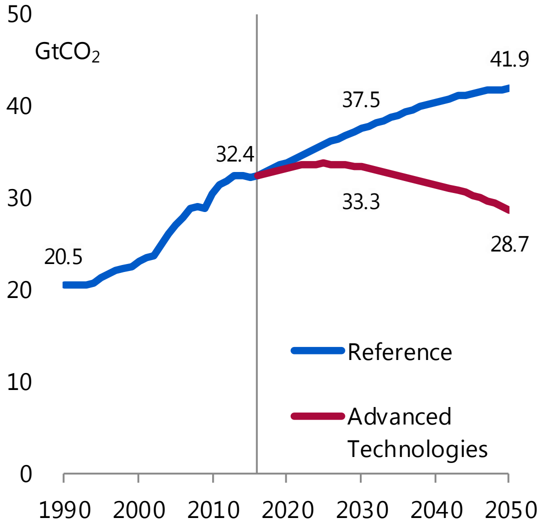
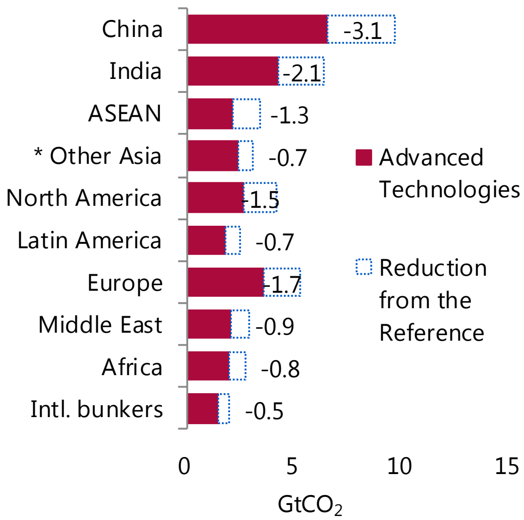


Figure 4-17 | CO_2 emissions [Advanced Technologies Scenario, 2050]



Note: Other Asia covers Oceania.

Of the emission decline from the Reference Scenario in 2050, energy efficiency improvement will account for the largest share at 5.3 Gt, followed by 3.8 Gt for renewable energy expansion, 2.0 Gt for carbon capture and storage (CCS) and 1.7 Gt for nuclear expansion (Figure 4-18, Table 4-7). About 40% of the emission decline will arise from the expansion of non-fossil power generation including renewable energy and nuclear power generation. CCS technologies are assumed to be introduced for all new fossil fuel-fired power plants to be built from 2030 in regions with potential for storing CO_2 excluding aquifers.

Figure 4-18 | Global CO_2 emissions reduction by measure

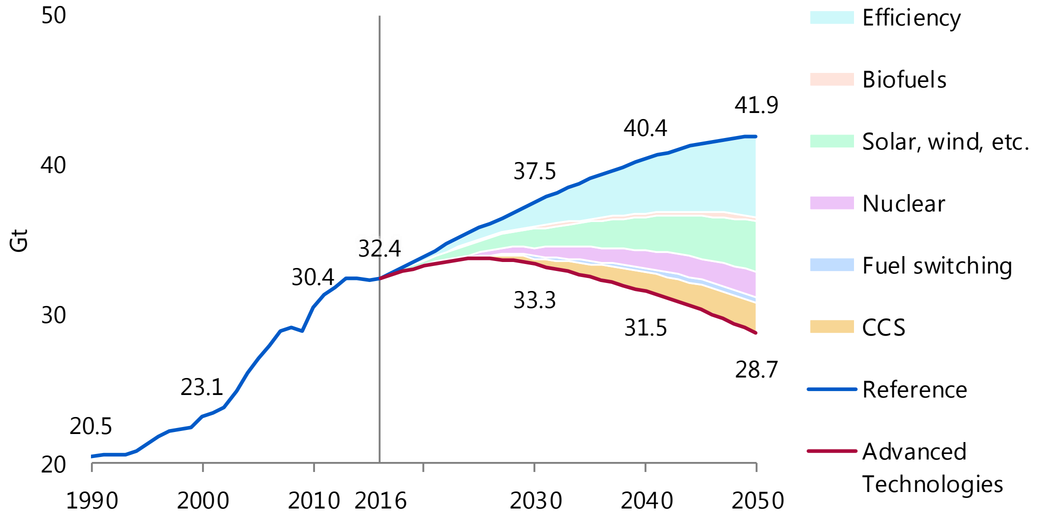


Table 4-7 | CO_2 emissions reduction from Reference Scenario [Advanced Technologies Scenario]

($GtCO_2$)

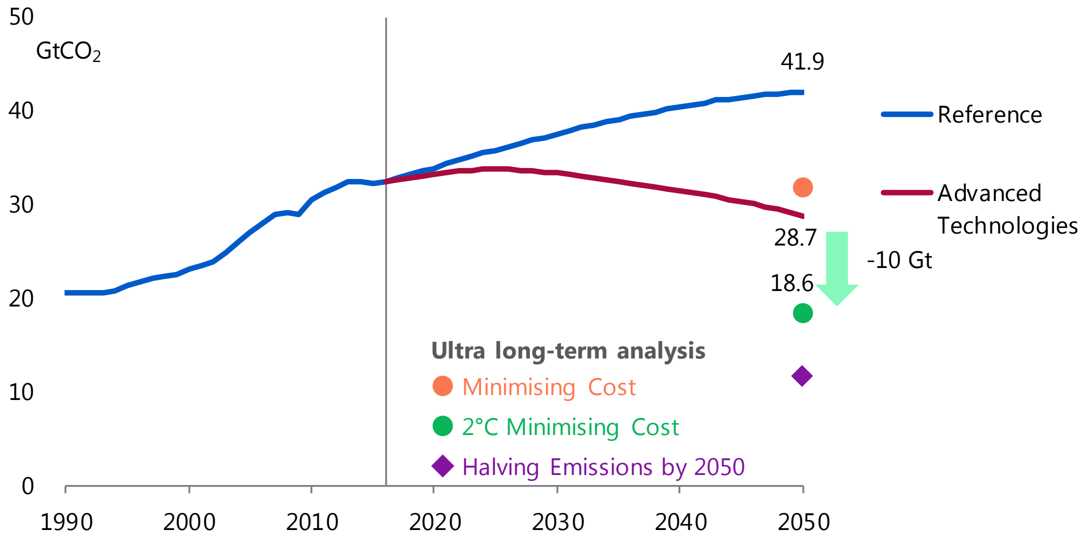
	2050		2017-2050 cumulative reduction	
	Reduction	Share	Reduction	Share
Energy efficiency improvement	5.3	40%	83.2	40%
Biofuels	0.3	2%	5.8	3%
Solar PV, wind, etc.	3.4	26%	55.4	27%
Nuclear	1.7	13%	27.1	13%
Fuel switching	0.4	3%	6.7	3%
CCS	2.0	15%	27.7	13%
Total	13.2	100%	206.3	100%

Each technology is imperfect, having both advantages and disadvantages. These technologies are easy or difficult to introduce, depending on local conditions. It is important to appropriately use various options without depending heavily on certain technologies or measures.

Cutting CO_2 emissions further

Energy-related CO_2 emissions in 2050 in the Advanced Technologies Scenario will fall by 11.2% from 2016, deviating far from the target of halving emissions in 2050. The CO_2 emission path in the Advanced Technologies Scenario is almost consistent with the "Minimising Cost Path" described in the IEEJ Outlook 2018 published in the previous year. If the temperature increase from the second half of the 19th century is to be limited to 2°C in 2150 (see the "2°C Minimising Cost Path" in IEEJ Outlook 2018), CO_2 emissions would have to be reduced by an additional 10 Gt from the Advanced Technologies Scenario in 2050.

Figure 4-19 | Global energy-related CO_2 emissions (comparison with ultra-long-term analysis)



Note: The ultra-long-term analysis represents results gained with an integrated assessment model (see the IEEJ Outlook 2018).

To reduce CO_2 emissions by an additional 10 Gt in 2050, a massive introduction of innovative technologies will be required. Technologies for limiting the temperature rise include not only energy conservation, renewable energy and nuclear technologies, but also next-generation nuclear power plants, space-based solar power, nuclear fusion, hydrogen utilisation, carbon capture and utilisation (CCU) and bioenergy with CCS (BECCS).

The replacement of non-CCS-equipped fossil fuel-fired power generation capacity with carbon-free hydrogen capacity and the introduction of fuel cell vehicles using carbon-free hydrogen have great potential to reduce CO_2 emissions. Carbon-free hydrogen may be produced through electrolysis using renewable energy-generated electricity or from fossil fuels through CCS-equipped facilities, emitting no CO_2 during production and consumption. Carbon-free hydrogen would be available through international trade for countries or regions that have no CCS storage potential.

Building materials and polymers for CCU are close to commercialisation. These CO_2 utilisation products have potential to utilise 1 $GtCO_2$ – 7 $GtCO_2$ in 2030. Negative emission technologies including bioenergy with carbon capture and storage (BECCS) could reduce CO_2 emissions by

12.1 Gt in 2100. If short rotation coppices (including willows and poplars) are used to supply biomass, 7% - 25% of agricultural land and 25% - 46% of arable plus permanent crop area will be required.

As a matter of course, any single technology alone may not have to be adopted for cutting CO_2 emissions by 10 Gt. These innovative technologies may be introduced compositely according to local conditions. Given that these technologies are required to spread massively by 2050, however, technology and cost challenges will have to be resolved in the next decade.

Table 4-8 | Costs and potential of innovative technologies to reduce emissions further

Technology	Costs	Potential
Next-generation nuclear reactors	About JPY4.2/kWh (Estimated for a commercial high temperature gas reactor system (Japan))	70 MW/unit - 600 MW/unit
Space-based solar power	JPY10/kWh (target cost)	1,300 MW/system
Nuclear fusion	€0.0627/kWh - €0.1883/kWh	700 MW/unit
Hydrogen utilisation	\$0.5-0.6/Nm3 (for electrolysis) Hydrogen price per calorie: About JPY1,800/toe	Hydrogen production from various resources indicates enormous potential
CO_2 capture and utilisation	Building materials and polymers are close to commercialisation	1 $GtCO_2$/year - 7 $GtCO_2$/year (CO_2 utilisation products in 2030)
Bioenergy with CCS (BECCS)	\$40/tCO_2 - \$100/tCO_2 (Model median price at \$36/tCO_2 for 2100)	12.1 $GtCO_2$/year (as of 2100)

Note: The emission reduction cost is JPY2,000/t CO_2 when the cost gap with a power source subject to substitution stands at JPY1/kWh and the emission factor for the power source subject to substitution at 0.5 $kgCO_2$/kWh.
Sources: IEEJ Outlook 2018; Bustreo, 2013, Fusion energy economics, 64th Semi-annual ETSAP meeting

Carbon budget

The carbon budget, or the maximum amount of CO_2 that can be released into the atmosphere to limit warming to a certain level toward 2100, has been controversial. The concept of the carbon budget was introduced before the 2009 COP9 meeting in Copenhagen. Then, peak warming was viewed as related to cumulative emissions but unrelated to any emission pathway. The IPCC 5th Assessment Report (2013) highlighted the importance of the carbon budget. In response, Miller et al (2017)[18] was published in the October 2017 issue of Nature Geoscience, attracting great interest by indicating that limiting warming to 1.5°C would be geophysically feasible and that the remaining carbon budget for the 1.5°C increase would be several times more than given by the IPCC earlier.

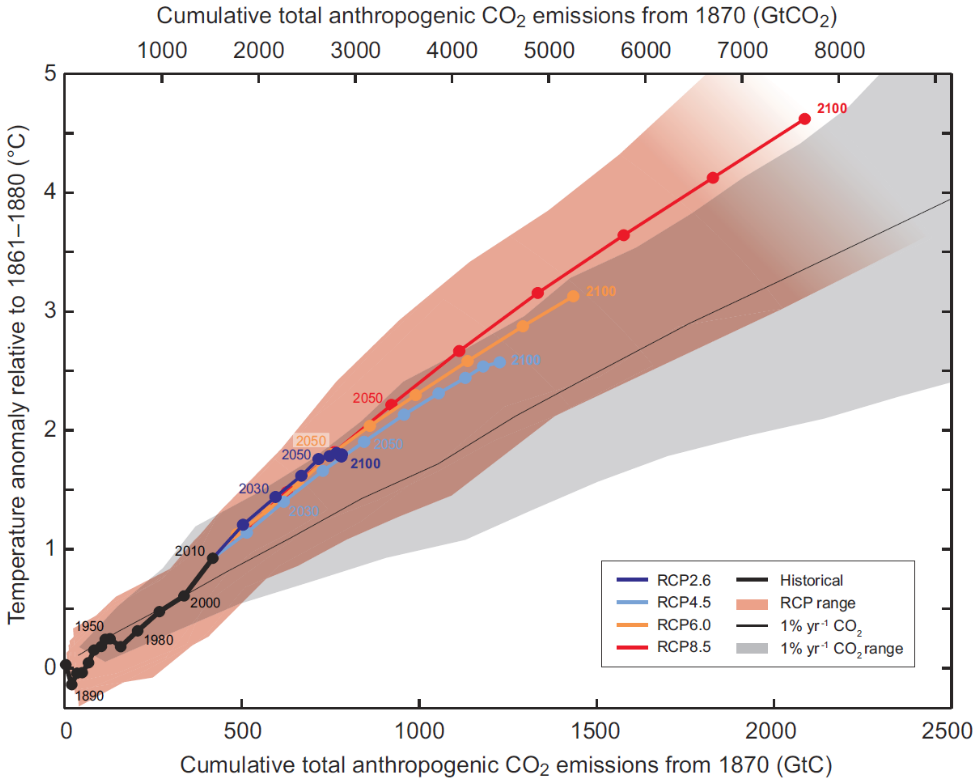
The following are excerpts from the IPCC 5th Assessment Report (2013):

> *Cumulative total emissions of CO_2 and global mean surface temperature response are approximately linearly related. Limiting the warming caused by anthropogenic CO_2 emissions alone with a*

[18] Miller, R. J. et al. *Nat. Geosci.* **10,** 741-747 (2017).

probability of 33%, 50%, and 66% to less than 2°C since the period 1861–1880 will require cumulative CO_2 emissions from all anthropogenic sources to stay between 0 and about 1,570 GtC, 0 and about 1,210 GtC, and 0 and about 1,000 GtC since that period, respectively. These upper amounts are reduced to about 900 GtC, 820 GtC, and 790 GtC, respectively, when accounting for non-CO_2 forcings as in RCP2.6[19]*. An amount of 515 GtC was already emitted by 2011.*

Figure 4-20 | Global mean surface temperature increase as a function of cumulative total global CO_2 emissions



Source: Summary for Policymakers, IPCC Working Group 1 Contribution to 5th Assessment Report

Miller et al. (2017) made the following points:

Human-induced warming reached an estimated 0.93°C above the 1861-80 level and pre-2015 cumulative carbon emissions came to 545 GtC. Both quantities differ from the mean response levels in the 5th Coupled Model Intercomparison Project (CMIP5) ensemble of Earth system models. The CMIP5 ensemble was analysed to assess the remaining carbon budget for an additional 0.6°C of warming beyond the 2010s in light of estimated human-induced warming and cumulative emissions to date. The median response of the CMIP5 models indicates allowable future cumulative emissions (TEB) [20] *of 223 GtC for a further 0.6°C warming above the 2010–2019 average and a 204 GtC*

[19] The RCP stands for Representative Concentration Pathway. RCP2.6 was selected from scenarios in which a certain radiative forcing level would be reached through a pathway including the temporal sequence of emission amounts and concentration levels. RCP2.6 represents the lowest radiative forcing level, indicating that radiative forcing would peak at 3 W/m² before 2100 and decrease later.

[20] Threshold-Exceedance Budget

remaining TEB from 2015 (the same as the method for assessing the 2°C carbon budget in the 5th IPCC Assessment Report, the 66th percentile of the CMIP5 distribution).

Given that the TEB does not apply to non-CO_2 forcing, however, the RCP2.6 scenario, in which non-CO_2 forcing across the rest of the 21st century remains close to the 2010–2019 average, was used for consideration. As the RCP2.6 scenario begins CO_2 emission reductions in 2010, it was amended to become more consistent with current emissions and estimated present-day climate forcing. The amended scenario, RCP2.6-2017, assumes the same proportional rates of change of both CO_2 and other anthropogenic forcing components as in the standard RCP2.6 scenario from 2010, with the mitigation start date delayed by seven years to 2017. The implications of this scenario for future warming were evaluated with a simple climate model that reproduces the response of the CMIP5 models. Peak warming under the RCP2.6-2017 scenario is likely between 1.24–2.03°C (1.12–1.99°C for 2100 warming) given a 2015 externally forced warming of 0.92°C. Using a central value of 1.6°C the TCR[21], the RCP2.6-2017 gives a median peak warming of 1.55°C and 1.47°C in 2100.

Accounting for the current uncertainty in the climate response, we considered a distribution of future temperature trajectories, for different climate responses, that are all consistent with a smooth transition to 1.5°C in 2100. Temperatures initially follow the responses to the RCP2.6-2017 scenario but are then smoothly interpolated over the coming century to the trajectory given by the best-estimate response. By deriving emission pathways from temperature trajectories and providing emission pathways consistent with temperature trajectories, we gave cumulative emissions (net carbon budgets) under the goal-consistent pathways. The median case corresponds to a cumulative budget of 370 GtC from 2015 to 2100, including up to 10 GtC of net negative emissions in the final decades. Allowing for temperature overshoots in the middle of the 21st century, the cumulative carbon budget from 2015 to 2100 ranges from 250 GtC to 540 GtC within a probability range of 33-67%. The lowest estimate of 250 GtC is 25% higher than a 204 GtC remaining TEB for the 66th percentile of the abovementioned CMIP5 distribution.

The lower limit of NDCs is consistent with global fossil-fuel and land-use change CO_2 emissions only slightly above 2015 values, close to the RCP2.6-2017 scenario. A modest strengthening of the pledges corresponding to an approximate 10% reduction in proposed 2030 emissions could achieve consistency with the RCP2.6-2017 scenario. However, the RCP2.6-2017 scenario implies decarbonization at over 0.3 GtC/yr in the 2030s and 2040s, or 4–6% per year sustained for multiple decades. Longer-term deep decarbonisation relies on many energy system innovations. Limiting warming to 1.5°C would be geophysically feasible.

The Miller et al. (2017) approach and its results were later reaffirmed by other papers.

The following table compares carbon budgets, or allowable cumulative CO_2 emissions, in the IPCC 5th Assessment Report (2013) and Miller et al. (2017).

[21] The TCR stands for Transient Climate Response, defined as the average change in global surface temperature over 10 years to and from the time of atmospheric CO_2 doubling in a global coupled ocean-atmosphere climate model simulation.

Table 4-9 | Comparison of carbon budgets at each warming threshold

		IPCC 5th Assessment Report (2013)	Miller et al. (2017)	
Warming threshold	Starting year for computing cumulative emissions	IPCC 5th Assessment Report approach		Miller et al. (2017) approach
1.5°C	2015	70 GtC (66% of models)	204 GtC (66%) 223 GtC (50%) 250 GtC (33%)	250 GtC (67%) 370 GtC (median) 540 GtC (33%)
2°C	2015		395 GtC (66%) 416 GtC (50%) 464 GtC (33%)	
	2012	275 GtC (66%) 305 GtC (50%) 385 GtC (33%)		

Note: Prepared from the IPCC 5th Assessment Report (2013) and Miller et al. (2017).

Given the above arguments, the world should not be complacent with the possibility of a greater remaining carbon budget than indicated earlier but proactively tackle the following measures to limit warming to 2°C or 1.5°C:

- Further considering carbon budgets to limit warming to certain levels, reducing climate response uncertainties
- Enhancing NDCs in 2030 to mitigate rapid decarbonisation required from 2030, promoting the objective assessment of NDCs to this end
- Focusing on research and development now to promote energy system innovation from 2030

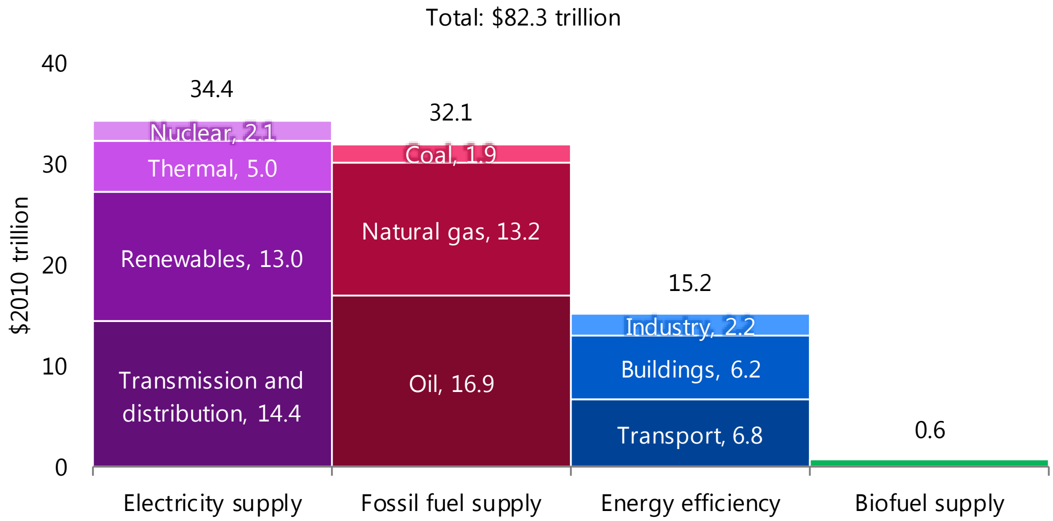
5. Energy-related investment

5.1 Reference Scenario

Global primary energy consumption will increase from 13.8 Gtoe in 2016 to 19.3 Gtoe in 2050 in the Reference Scenario. As the energy consumption growth is remarkable in emerging economies, they will have to raise and implement massive investments in resource developments, in fuel transportation and in power generation, transmission and distribution capacity. Regions with sufficient capacity will need to replace existing capacity and invest in energy efficiency improvement. In the Reference Scenario, $82.3 trillion (2010 dollars, the same hereinafter) in energy-related investment[22] will be required over 34 years from 2017 to 2050 (Figure 5-1).

Of that total, $32.1 trillion or more than 40% will be related to fossil fuel investments (oil, natural gas and coal). Most of the investment will support production, with the remainder spent on refining, transportation and natural gas liquefaction. In the future, fossil fuel-related investment will continue to account for a major share of energy-related investment and any fossil fuel divestment could threaten the stability of the energy supply. The way should be paved and maintained for supplying enough funds for the necessary resources development.

Figure 5-1 | Global energy-related investment [Reference Scenario, 2017-2050]



The power generation sector's investment will account for $34.4 trillion or 42% of the total. Of the power generation sector's investment, renewable energy power generation will capture

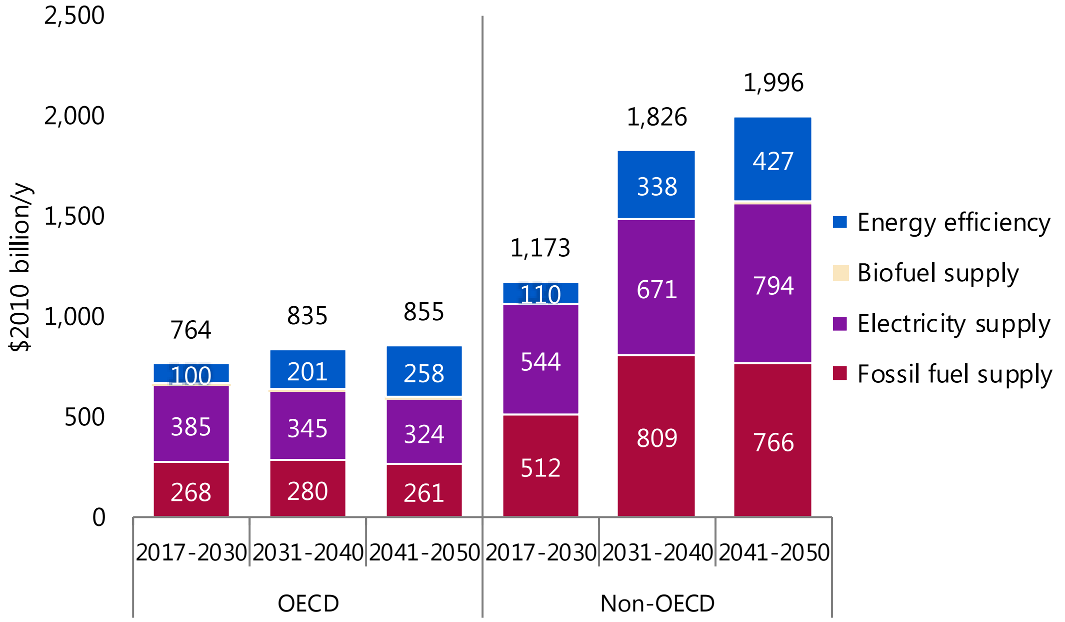
[22] Energy-related investment in this chapter covers resources (oil, natural gas and coal) development, oil refining, fuel transport (oil, natural gas and coal), natural gas liquefaction, biofuels, fossil fuel-fired power generation (coal, natural gas and oil), nuclear power generation, renewables (solar photovoltaics, wind, hydro, geothermal heat, biomass, solar heat and marine energy), CCS, power transmission, power distribution, and energy-efficient equipment or products (transport, buildings and industry sectors).

16% (including 5 percentage points for wind, 3 points for solar photovoltaics, 5 points for hydro and 2 points for others). Investment in fossil fuel-fired power generation will command 6%. As investments in coal-fired power generation will decrease every year, those in natural gas-fired power generation will steadily increase covering for the fall in coal-fired power generation investment. Investment in power transmission and distribution will account for 17% of the total investment. Final electricity consumption in 2050 will total 40,477 TWh, up 1.9-fold from 2016. In developing countries where electricity demand will expand rapidly, a large portion of the investment will be required for the expansion of their electrified areas and for higher voltage power lines.

On the demand side, $15.2 trillion must be invested in energy efficiency improvement by 2050, accounting for 18% of the total energy-related investment. The sum includes $6.8 trillion for the transport sector, $6.2 trillion for the buildings sector and $2.2 trillion for the industry sector.

OECD and non-OECD energy-related investment trends will differ from each other. While both annual OECD and non-OECD investment values will continue to rise, non-OECD investment will grow faster (Figure 5-2). In OECD that will implement more climate change countermeasures, zero-emission power sources such as nuclear and renewables and demand side's energy efficiency improvement will account for larger shares of overall energy-related investment than in non-OECD. In non-OECD, including those with underdeveloped power infrastructure, massive investments will be required in power generation, transmission and distribution facilities to meet the rapid growth in electricity demand.

Figure 5-2 | Energy-related investment [Reference Scenario]

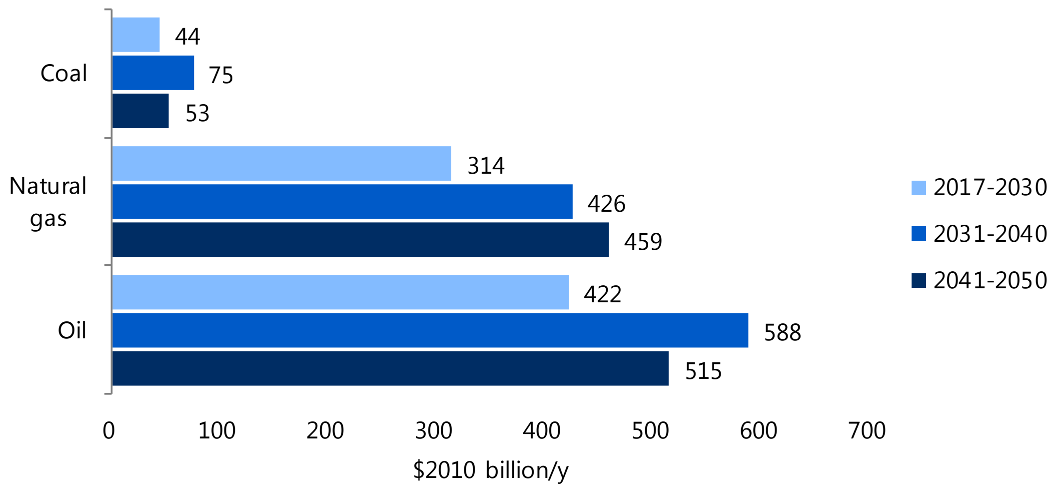


In both OECD and non-OECD, investment in fossil fuel production will peak in the 2030s and decrease later, though still accounting for a large share of total energy-related investment. Investments in power facilities will decrease gradually in OECD that already have enough capacity and will expand power demand moderately. Investments in non-OECD will increase year by year to satisfy a rapidly growing energy demand. Demand-side investment in energy efficiency improvement will be the only energy-related investment component that will continue to increase in OECD, accounting for 30% of total OECD energy-related investment in the 2040s.

5.2 Fossil fuel investment

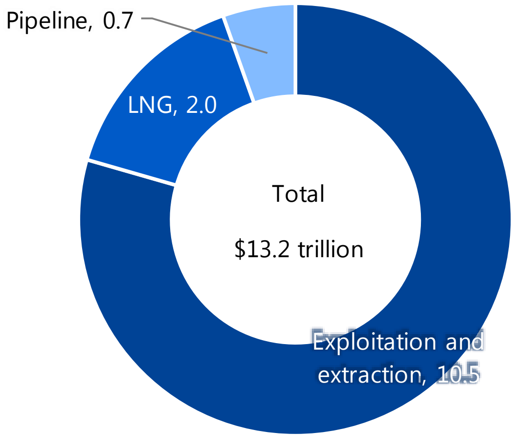
Fossil fuel investment will rapidly expand until the 2030s before decreasing moderately later. Even in the 2040s, such investment will still exceed $1 trillion per year, accounting for the mainstream of total energy-related investment. As primary coal consumption turns downward in the 2040s, coal investment will begin to decline (Figure 5-3). Oil production growth will continue but slow down, resulting in a fall in investment in new capacity. In line with the fall, oil investment will turn downward in the 2030s. However, investment in rapidly expanding natural gas production will increase until 2050.

Figure 5-3 | Global fossil fuel investment [Reference Scenario]



As natural gas consumption increases, production, transport and liquefaction capacity will need to expand. Of the natural gas investment totalling $13.2 trillion through 2050, resources development will account for $10.5 trillion or 80% (Figure 5-4) and as LNG trade expands, $2 trillion will have to be invested in LNG-related equipment including production facilities and tankers.

Figure 5-4 | Global natural gas investment [Reference Scenario]



5.3 Electricity investment

Power generation equipment

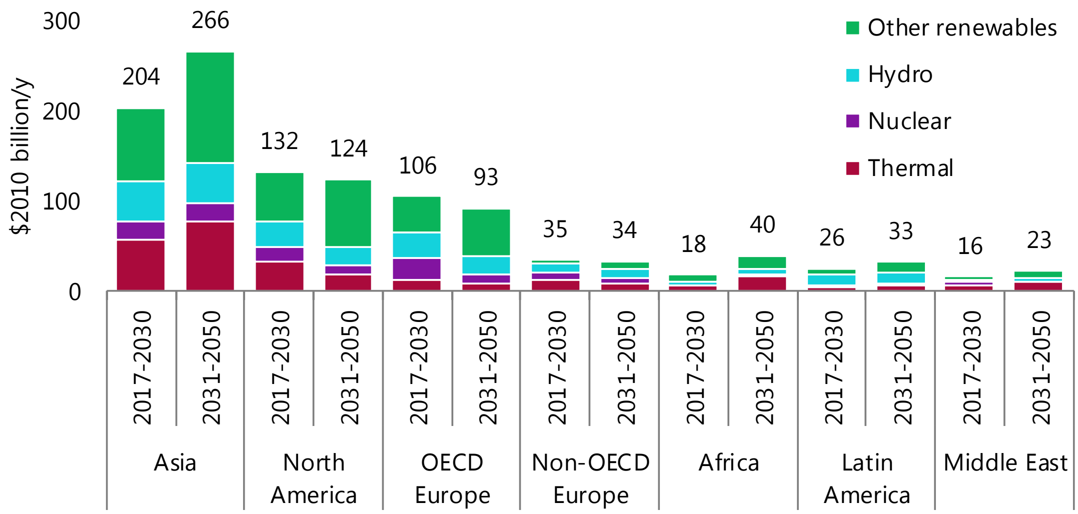
Investment in power generation equipment will continue expanding, totalling $20 trillion through 2050. Coal-fired power generation investment, however, will turn downward in the 2020s. Particularly, OECD investment in coal-fired power generation will decline sharply due to the United States' switching to natural gas-fired power generation and a coal phase-out policy in the United Kingdom and Canada. In both OECD and non-OECD, investment will expand year by year in natural gas-fired power generation that will capture nearly 30% of total power generation in 2050. While nuclear power generation capacity will expand year by year, investment in nuclear power generation will follow a downward trend due to cost cuts through technological advancement after the intensification of new nuclear power plant construction in the 2020s.

Investment in renewable energy power generation will substantially expand through 2050. Annual investment required in the 2040s will reach $120 billion for hydro, $90 billion for solar photovoltaics and $160 billion for wind, surpassing investment in nuclear power generation. Renewable energy equipment costs have already declined substantially and will continue to follow a downtrend in the future. Nevertheless, investment in renewable energy equipment will retain an uptrend.

Power generation equipment investment strongly reflects regional differences (Figure 5-5). In North America and OECD Europe, including many developed countries, such investment will follow a downtrend. Particularly, investment in fossil fuel-fired power generation will post a remarkable decline. While overall power generation equipment investment will shrink, renewable energy power generation investment will continue to increase through 2050. These regions, though with moderate power demand growth, will become a key market for renewable energy power generation equipment.

In Asia, Africa and the Middle East including many developing countries, rapid growth in investment in power generation equipment will be required to meet power demand expansion. These regions will have to expand investment in fossil fuel-fired as well as other types of power generation facilities, continuing to increase annual power generation investment. How to raise sufficient funds to cover such investment and how to address at the same time the environmental issues accompanying fossil fuel-fired power generation will become key challenges for the development of emerging economies.

Figure 5-5 | Power generation equipment investment in selected regions [Reference Scenario]

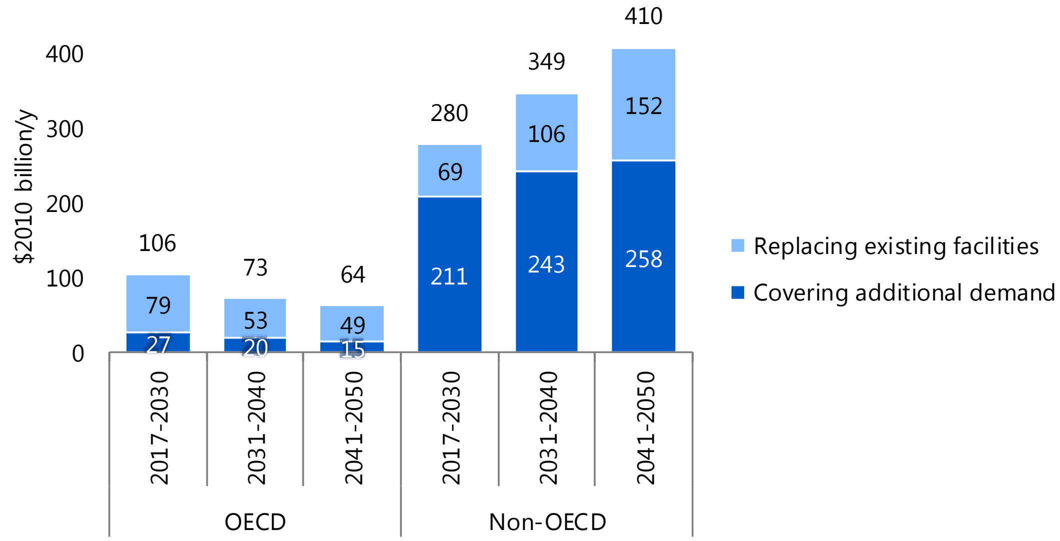


Power transmission/distribution equipment

Investment required in power transmission and distribution equipment through 2050 will total $14.4 trillion, amounting to three quarters of the power generation equipment investment. Not only investments in power generation equipment but also significant investments in transmission and distribution equipment will be required for meeting the rapid power demand growth.

The trend of power transmission and distribution equipment investment in developed countries will contrast with that in developing countries (Figure 5-6). In OECD where power transmission and distribution networks have already been appropriately developed to meet power demand, the investments will decrease year by year, and will mainly be for covering the replacement cost of outdated equipment. In non-OECD where final electricity consumption will grow at an annual rate exceeding 2.0%, power transmission and distribution equipment investment will expand year by year, focusing on expansion to meet the growing power demand. Power transmission and distribution equipment investment will account for only 10% of overall investment in OECD, against 21% in non-OECD. The prompt development of power transmission and distribution networks is a key challenge for emerging economies over the next several decades. They will be required to smoothly raise funds, secure lands and create legal systems to realise the development.

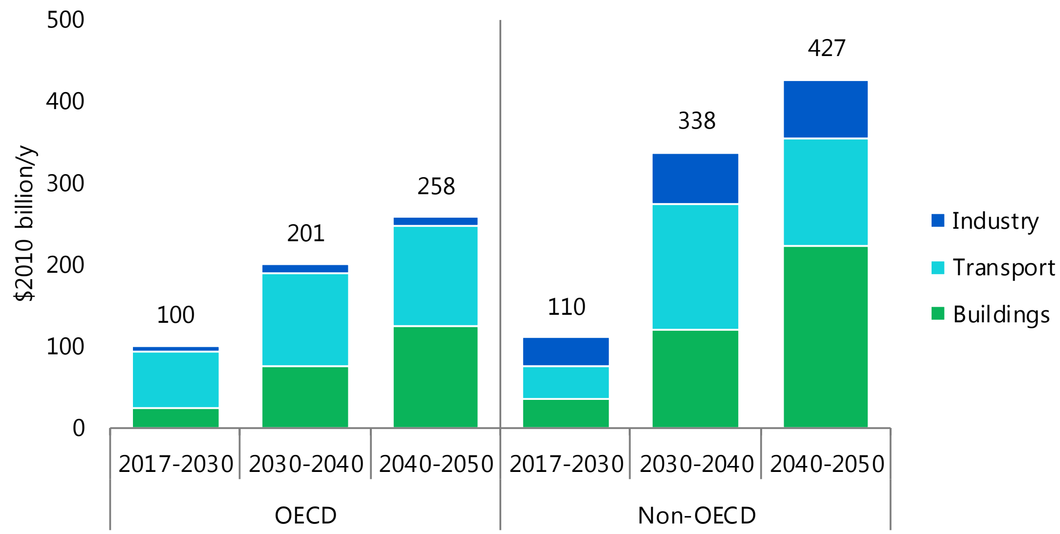
Figure 5-6 | Investment in power transmission and distribution equipment [Reference Scenario]



5.4 Demand-side investment in energy efficiency improvement

Demand-side investment in energy efficiency improvement[23] will increase year by year, reaching a total of $15.2 trillion through 2050 (Figure 5-7).

Figure 5-7 | Investment in energy efficiency improvement [Reference Scenario]



[23] Investment in energy efficiency improvement is defined as a gap between prices paid for a traditional product and a more efficient one. The investment defined in this way fails to explicitly include technological development investment costs but prices for more efficient products can be interpreted as covering such costs.

Investments in the buildings sector will reach $6.2 trillion in energy efficiency improvement in the next 34 years. The sum includes $3.6 trillion for the residential sector and $2.6 trillion for the commercial sector. Investment in energy efficiency improvement will increase year by year in both those sectors. Of such investment, air-conditioning and insulation efficiency improvement will account for about 50% in the residential sector and for more than 80% in the commercial sector. Technological development and cost reduction for air-conditioning equipment and insulation will hold the key to energy efficiency improvement in the sector.

The road sector will require investments of $6.8 trillion in energy efficiency improvement, of which most will be for passenger cars. In 2050, hybrid vehicles will account for 27% of passenger cars in the world and electric vehicles (including plug-in hybrid vehicles) for 10%. Including fuel efficiency gains for internal combustion vehicles, the sector's fuel efficiency improvement will make great progress. The average travel distance per unit energy consumption in 2050 will be 1.5 times as long as the present level.

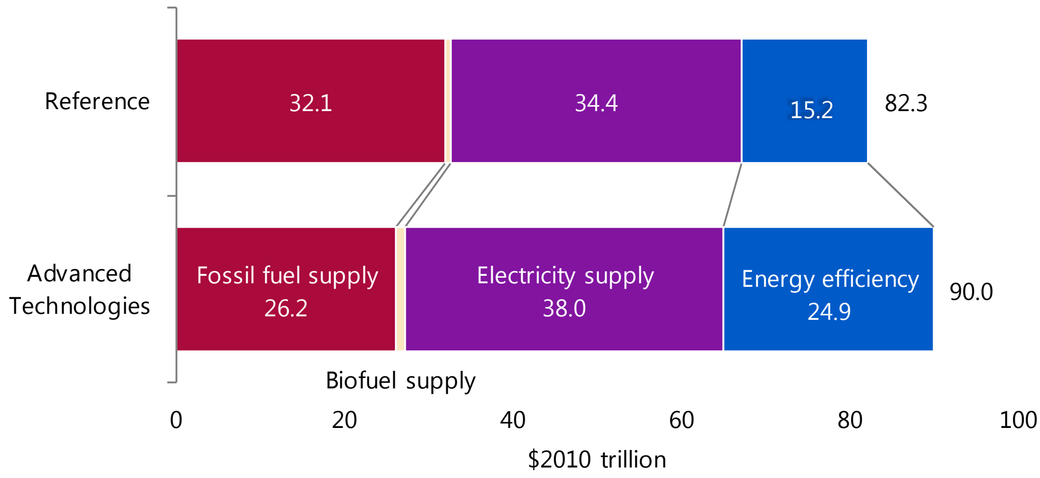
Developed countries' share of investment in energy efficiency improvement will be greater than their share of any other energy-related investment component. The North American and OECD Europe share of investment in energy efficiency improvement will be larger than that of investment in power generation and will retain an uptrend through 2050. In North America where vehicle ownership is high and in OECD Europe where ambitious electric vehicle diffusion targets are set, robust investment in energy efficiency improvement will be required over the next few decades.

5.5 Climate change countermeasures – investment and its effects

Cumulative energy-related investment in the Advanced Technologies Scenario will total $90 trillion, $7.7 trillion more than in the Reference Scenario (Figure 5-8). In contrast, cumulative CO_2 emissions in the Advanced Technologies Scenario will be 206 Gt less than in the Reference Scenario. By dividing the additional investment in the Advanced Technologies Scenario by the CO_2 emission reduction, we can estimate an average investment value for cutting emissions. To realise the Advanced Technologies Scenario, an average investment of $37 per tonne of CO_2 emission cut will be required.

Fossil fuel investment in the Advanced Technologies Scenario will be equivalent to some 80% of the Reference Scenario level. Particularly, coal investment will decrease from the Reference Scenario by $0.6 trillion to $1.3 trillion. Even so, fossil fuel investment in 2050 will be more than at present. If fossil fuel development investment declines too rapidly for environmental or other reasons, the stability of the energy supply may be affected. Financial institutions, investors and policymakers will be required to make wise decisions for the so-called 3Es + S (energy security, environmental conservation and economic efficiency plus safety).

Figure 5-8 | Global energy-related Investment [2017-2050]



Power generation in 2050 in the Advanced Technologies Scenario will be 3,700 TWh less than in the Reference Scenario. However, investment in power generation, transmission and distribution facilities through 2050 would increase by $3.6 trillion from the Reference Scenario to $38 trillion. This is because higher-cost renewable energy and nuclear power generation facilities will replace fossil fuel-fired facilities (including coal-fired ones). In the Advanced Technologies Scenario, renewable energy investment will account for most of OECD and non-OECD power generation investment (Figure 5-9). Particularly, investment in wind and solar PV power generation will expand year by year. Investment in fossil fuel-fired power generation will remain almost unchanged from the present level in non-OECD while shrinking year by year in OECD. Developed countries will be required to pave the way for emerging economies to expand low-carbon power sources, choose more efficient and lower-load fossil fuel-fired power generation equipment and implement investment in a manner to recover investment as much as possible.

Demand-side investment in energy efficiency improvement through 2050 will total $24.9 trillion, up $9.7 trillion from the Reference Scenario. The buildings sector will account $5.6 trillion or the largest share of the increase from the Reference Scenario (Figure 5-10). Meanwhile, the three sectors' total energy consumption through 2050 will decrease by 26,000 Mtoe from the Reference Scenario. Additional investment per toe in energy savings will differ from sector to sector, standing at about $700/toe in the buildings sector, at about $400/toe in the transport sector and at about $100/toe in the industry sector. Given that energy prices in the buildings sector are relatively higher, higher investment in energy efficiency improvement in the sector will be, to some extent, economically acceptable.

Figure 5-9 | Power generation equipment investment [Advanced Technologies Scenario]

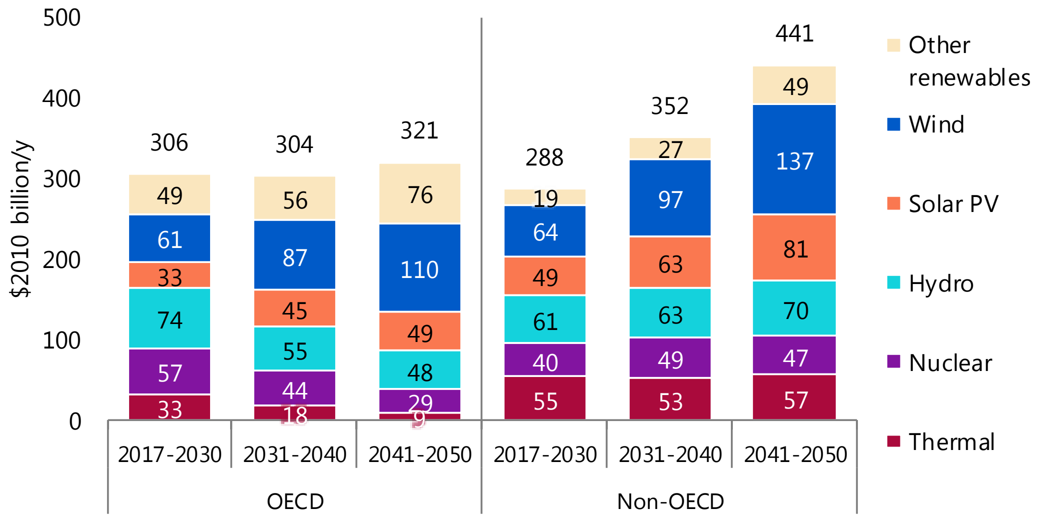
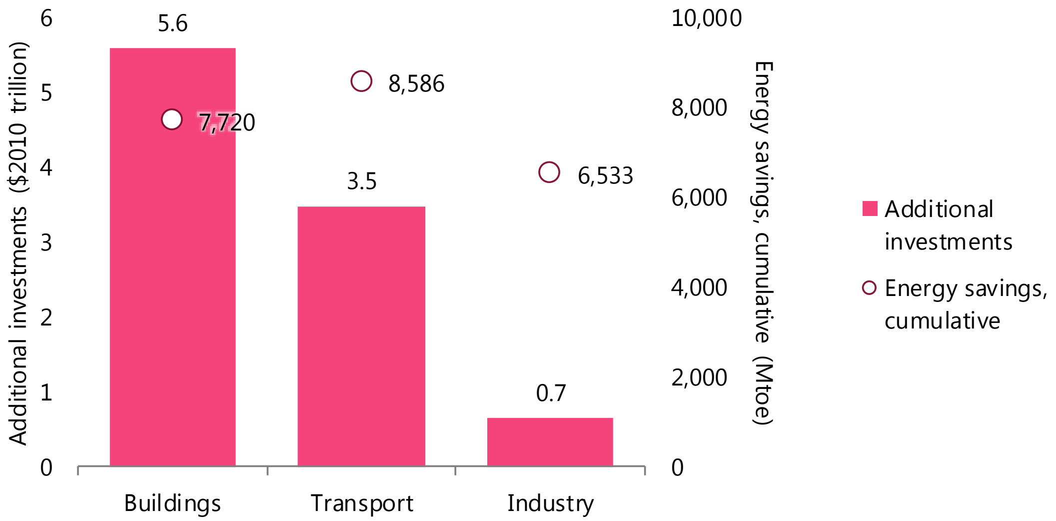


Figure 5-10 | Additional investment in energy efficiency improvement and cumulative energy savings [from Reference Scenario, 2017-2050]



Part II

Issues of energy security

6. Risks and impacts of energy supply disruptions

Most people living in developed countries are not aware of the energy required to support their daily life. People happily and freely use energy, indispensable for their daily needs and economic activities, without being conscious of the infrastructure supporting it. Occasionally as shown by history, however, energy supply can be disrupted and for many countries of the world, a stable supply of energy does not exist. This chapter reviews supply disruptions for oil that has been traditionally been discussed as subject to supply disruptions, and disruptions for electricity that has been increasingly used for social and economic activities and will be in growing demand due to climate change countermeasures as well as digitalisation including the expansion of the Internet of Things and artificial intelligence.

6.1 Oil supply disruptions

Case of supply disruptions and their causes

Oil supply disruption risks are considered for each stage of the supply chain here (Table 6-1).

Table 6-1 | Oil supply disruption risks and examples

	Risks	Examples
Production	Destruction or shutdown of production facilities due to unanticipated events such as accidents, failures and natural disasters Destruction of production facilities and suspension of operations due to political upheavals and terrorism Halting exports by political will or strategy	1973: OAPEC countries imposed an embargo on exports to the United States and the Netherlands. 2005: Hurricanes shut down oil production facilities in the U.S. Gulf Coast 2018: Exports of crude oil from Libya were partially reduced because of suspension of production and the blockade of ports due to internal strife.
Transport	Destruction or shutdown of facilities due to unanticipated events such as accidents, failures and natural disasters Destruction or suspension of transport means (ships, pipelines, etc.) by terrorism or piracy Interruption of transport routes by political will, strategy or military action	1984-1988: The “tanker war” by Iran and Iraq 2011: Destruction of natural gas pipelines from Egypt to Israel by terrorist attacks 2018: Attacks on crude oil tankers by Yemeni militants
Disruption / supply	Destruction or shutdown of supply facilities due to unpredictable events such as accidents, failures and natural disasters Destruction of supply facilities and suspension of operations due to terrorism	2011: Oil supply suspension due to the damage to oil refineries and oil depots and the destruction of ports, railways and roads caused by the Great East Japan Earthquake

Supply disruptions at the production stage range from the 1973 oil crisis to Libya’s suspension of crude oil exports in 2018. They include unanticipated disruptions caused by accidents, failures and natural disasters. Unanticipated disruptions occur with a certain probability not only at the production stage but also at any of the other stages in the supply chain and cannot be avoided completely. The impacts of such disruptions can be mitigated through technical measures such as the multiplexing of facilities. In contrast, it is difficult to take any fundamental countermeasures against disruptions resulting from the destruction of facilities because of political upheavals, terrorist attacks or disruptions caused by strategic intentional export suspensions, even when predictable and anticipated. Measures to reduce such risks include the diversification of import sources and the stockpiling of oil.

Apart from these risks, the production stage features structural risks, which would rarely lead to any sudden, large-scale supply disruption but retain influence over a long period of time. Examples of specific structural risks include the decline in recent years of Venezuelan crude oil exports. Venezuelan crude oil production began a downtrend in 2008. The decline rate accelerated because of the misgovernment that followed the death of then President Hugo Chavez in 2013 and because of weak crude oil prices since 2014. Its crude oil production has been continuously falling as investment for maintenance and increased production stalled, due to ballooning budget deficits and economic confusion. As the production fall has arisen from structural factors involving the country's entire society and economy, it is a kind of disruption difficult to address.

The transport stage also entails risks. Chokepoints, such as the Strait of Hormuz, have traditionally represented the largest risk for maritime oil transport. The provision of security for ships at those chokepoints has proven difficult. Terrorist and piracy attacks pose threats to oil tankers while oil pipelines can be subject to direct terrorist attacks or international political actions (including strategic export suspension).

Domestic supply disruptions attracted little attention in Japan before the situation dramatically changed with the Great East Japan Earthquake. Earlier disruptions caused by natural disasters had exerted only geographically limited consequences. The great disaster, however, triggered disruptions that affected a wide range of geographical area, making it difficult to provide sufficient amount of backup in a timely manner. For example, multiple oil refineries and tanks simultaneously became unavailable while ships, railways and tanker trucks for oil transport to disaster-affected regions also faced difficulties.

Economic impacts of supply disruptions

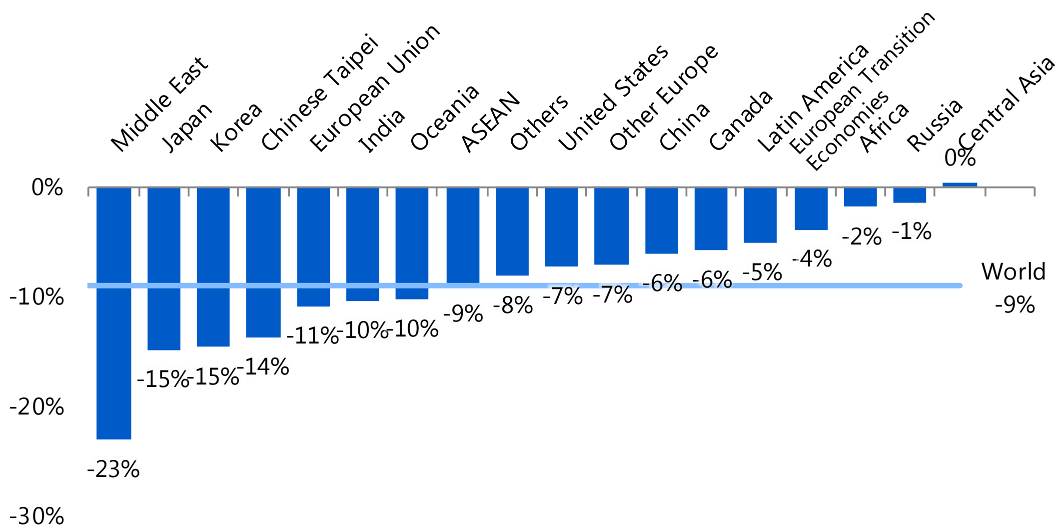
What would the economic impacts of an oil supply disruption be? Here, we would like to estimate the impacts of a Middle Eastern oil production decline of 10 Mb/d that may not be covered by any other region[24].

A large-scale supply disruption would lead to a contraction of the global economy of 9% (Figure 6-1). The global financial crisis of a decade ago reduced global economic growth by 2.3

[24] For the estimation, we use the Global Trade Analysis Project model, one of the representative applied general equilibrium models. An oil supply disruption can not only boost prices of oil by collapsing the supply-demand balance for the good but also affect each economic agent's activities in each region by changing relative prices of other goods and production activities and transferring income and production factors. See Asia/World Energy Outlook 2016 for details.

percentage points from the previous year in 2008 and by 3.5 points in 2009[25]. The Middle Eastern oil supply disruption would most seriously affect Japan, Korea and Chinese Taipei among non-Middle Eastern economies. These economies heavily depend on oil and feature greater oil supply dependence on the Middle East than Western economies. In India that heavily depends on coal and the European Union that depends less on the Middle East for oil supply, economic contraction would be less than in Japan, Korea or Chinese Taipei but still exceed 10%. The Middle Eastern oil supply disruption would exert less impacts than the global average on the United States that is expanding oil production, leading the U.S. economy to contract by some 7%. The impact on China, located in East Asia including Japan, Korea and Chinese Taipei, would be relatively limited because the country, though being the world's second largest oil consumer, depends heavily on coal and is the first largest oil producer in Asia and the eighth largest in the world.

Figure 6-1 | Impacts on real GDP of a 10 Mb/d decline in crude oil production in the Middle East



Russia, Africa, Latin America and Canada, though being net oil exporters, would not be free from the impacts. Although their net crude oil exports would expand on price hikes[26], their real GDP would contract by 1% - 5% on global economic contraction. These economies would get relative gains, however, no economy other than Central Asia would get an absolute gain.

Box 6-1 | Iranian situation's impacts on international oil market

When vowing to withdraw the United States from the Iran nuclear deal in May 2018, U.S. President Donald Trump announced the return of all Iran economic sanctions. The United States has asked oil importing countries to cut imports from Iran to zero. A decline in Iranian oil exports (now at 2.5 Mb/d) is expected to seriously affect the stability of the international oil market and oil prices. We used a scenario planning approach to analyse

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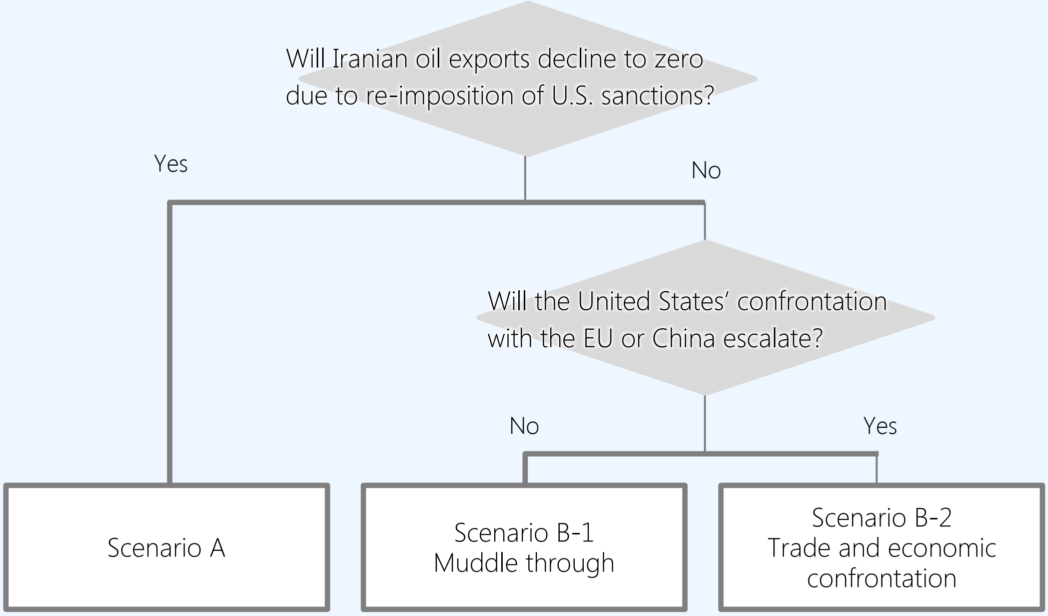
25 IMF "World Economic Outlook Database"

26 The price hikes would emerge from the supply-demand balance change and exclude speculative increases.

the impact of the Iranian situation on the international energy market through around 2020.

Figure 6-2 | Scenario bifurcations and key points of international oil / energy market



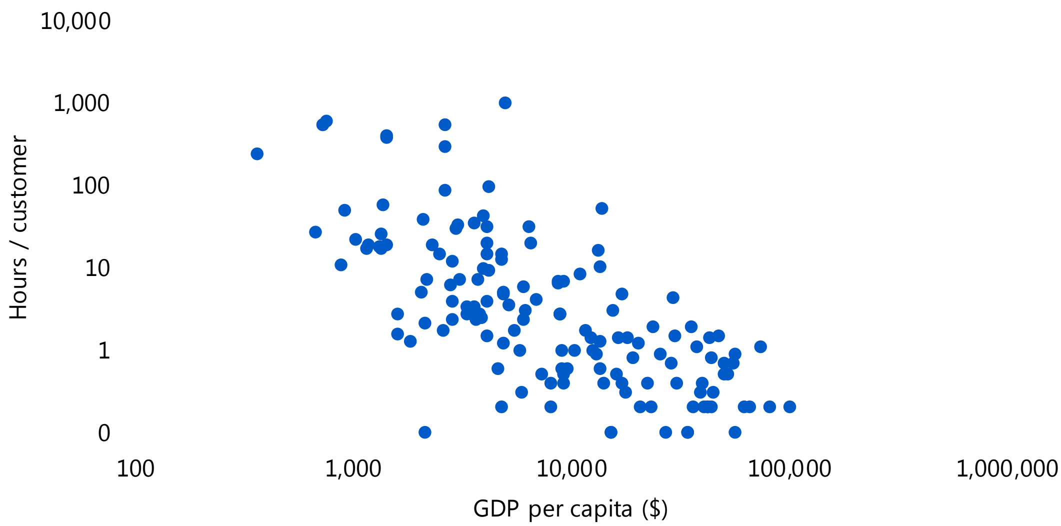
	Scenario A	Scenario B-1	Scenario B-2
Crude oil market	The supply-demand balance will tighten, with spare production capacity declining.	The market will be relatively calm thanks to production expansion by Saudi Arabia, etc.	Economic deceleration will lead to oversupply
Oil prices	Ranging from \$80/bbl to \$100/bbl. Rising above the range depending on the situation.	Ranging from \$70/bbl to \$80/bbl	Falling to \$50/bbl
Other energy markets	As LNG prices as well as oil prices rise, coal will get a price advantage	-	An LNG price fall will stimulate LNG demand. Final investment decisions on new LNG projects will be put off.

6.2 Electricity supply disruptions

Realities of disruptions

An electricity supply disruption takes the form of a power outage. Internationally, power outages vary widely by region. The duration of power outages per customer is longer in sub-Saharan Africa, island countries and South Asia. According to a World Bank survey in 2015, the duration of power outages exceeded 1,000 hours (11% of a year) in Comoros, Eritrea, Iraq, Nigeria, Pakistan, South Sudan and Eswatini (former Swaziland) (Figure 6-3). In developed countries, the annual duration of power outages per customer often slips below one hour. In regions including large cities, particularly, the duration is limited to several minutes.

Figure 6-3 | Income levels and outage duration [2015]



Sources: World Bank "Doing Business database" and "World Bank Open Data"

United States

Usually, large-scale power outages are caused by natural disasters. In the United States, power outages have frequently been triggered by hurricanes, winter storms and other large-scale natural disasters. The largest ever outage in the United States was the Northeast blackout of 2003. Cumulative outages in the year were equivalent to as much as 9.1% of peak power demand. However, electricity was restored within 43 hours (less than 30 hours in New York City), limiting the impacts on overall energy supply and demand.

In a recent large outage, Hurricane Harvey in August 2017 destroyed power distribution facilities and forced power plants to suspend operation. The outage primarily attributable to the destruction of distribution facility affected some 2.02 million customers in Texas, Louisiana, Mississippi and Arkansas. Some regions took as long as 12 days to restore electricity. The blackout came on the destruction of more than 850 transmission facilities, more than 6,200 power poles and more than 90 substations; the suspension of power generation capacity totalled more than 214.35 GW. Although Texas, located in the affected region, had massive wind mills back then, the frequency fluctuations were limited to usual ranges to avoid any large blackout attributable to a supply-demand imbalance, despite steep output fluctuations (several of them measured some 1 MW per hour). As the hurricane also destroyed roads and steel towers, a total of 12,000 people undertook restoration, achieving restoration promptly in two to 12 days[27]. As the United States has upgraded its electricity supply facilities with automated distribution, it is able to restore supply to most customers in several days, even in

[27] Source: North American Electric Reliability Corporation "Hurricane Harvey Event Analysis Report" March 2018

the face of outages attributable to equipment breakdowns accompanying large-scale natural disasters.

Table 6-2 | Large U.S. blackouts

	Natural disasters	Blackout-affected regions and scales
5 July 2012	Ohio Valley & Mid-Atlantic Summer Storm (wide-area thundershowers)	About 616,000 customers were affected in Illinois, Indiana, Maryland, New Jersey, Ohio, Virginia and West Virginia.
5 September 2012	Hurricane Isaac	About 14,000 customers were affected in Louisiana.
6 November 2012	Hurricane Sandy	About 930,000 customers were affected in Connecticut, Maryland, New Jersey, New York, Pennsylvania and West Virginia.
11 February 2013	Northeast Blizzard	About 136,000 customers were affected in Connecticut, Massachusetts, New York and Rhode Island.
6 December 2013	Winter storm	About 286,000 customers were affected in Arkansas, Missouri, Oklahoma, Tennessee and Texas.
13 February 2014	North American winter storm	About 742,000 customers were affected in Alabama, Florida, Georgia, Louisiana, New Jersey, North Carolina, Pennsylvania, South Carolina, Tennessee, Texas and Virginia.
17 August 2015	Typhoon Soudelor	About 14,000 customers or 4 MW were affected in Saipan (sweeping blackout).
7 October 2016	Hurricane Matthew	About 420,000 customers were affected in Florida.
26 August 2017	Hurricane Harvey	About 2.02 million customers were affected in Texas, Louisiana, Mississippi and Arkansas.

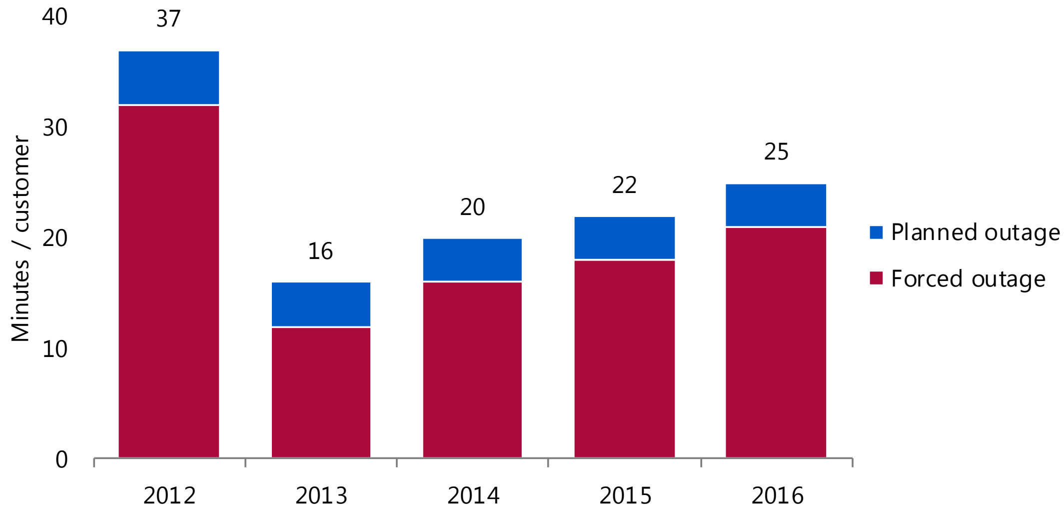
Source: Office of Electricity Delivery and Energy Reliability, Department of Energy “Emergency Situation Reports”

Even in developed countries, the introduction of power distribution automation systems to remotely control distribution facilities had been limited to urban regions. Under the Obama administration’s Green New Deal policy in 2008, a global smart grid boom came, with federal subsidies used for promoting power distribution automation. In California that has stepped up such automation, Pacific Gas & Electric Co. says that it has reduced the state’s outage duration. In regions featuring longer outage durations, automation of power distribution is effective for shortening outage durations.

Japan

In Japan, the Organization for Cross-regional Coordination of Transmission Operators (OCTTO) has published a Report on the Quality of Electricity Supply annually since FY2012. Japan annually experiences more than 10,000 power outages including those involving low-voltage power. Outages have mostly been caused by power distribution system difficulties and been limited in scale. Typhoons, rain storms and other natural disasters occasionally increase the frequency of relatively large outages.

Figure 6-4 | Average power outage duration per low-voltage customer in Japan



Source: Organization for Cross-regional Coordination of Transmission Operators, Japan "Report on the Quality of Electricity Supply" November 2017

In recent developments, large blackouts occurred in the service areas of Kansai Electric Power Co. and Chubu Electric Power Co. due to Typhoon Jebi or No. 21 on 4 September 2018, and in Hokkaido due to the 2018 Hokkaido Eastern Iburi Earthquake on 6 September. In the Kansai Electric Power service area that was hit hard by the typhoon, prompt restoration operations allowed electricity to be restored in two days for 90% of outage-affected households. In some areas where fallen trees affected road transportation, however, blackouts were more prolonged. The 2018 Hokkaido Eastern Iburi Earthquake forced the Tomato-Atsuma coal-fired power station located near its epicentre to be shut down, leaving the whole of Hokkaido without power. As the power station accounted for a half of Hokkaido's power supply capacity in the low-load season, full electricity restoration was delayed.

Box 6-2 | Blackout and tight supply-demand balance associated with the 2018 Hokkaido Eastern Iburi Earthquake

(1) Process to blackout and restoration

As the 2018 Hokkaido Eastern Iburi Earthquake occurred at 3:08 a.m. on 6 September 2018, and simultaneously forced Units 2 and 4 of the Tomato-Atsuma power station to suspend operation, a frequency decline triggered outages in some areas. An emergency frequency control system for an interconnection between Hokkaido and Japan's main island of Honshu worked to transmit 600 MW of electricity and maintained the interconnection until 3:25 a.m., when Unit 1 of the power station ceased operation on failure, spreading the blackout throughout Hokkaido.

Hokkaido Electric Power Co.'s power transmission and distribution division was prepared with spinning reserve capacity covering some 3% of local power demand and the emergency frequency control system (for transmitting 600 MW of electricity) for the Hokkaido-Honshu interconnection to respond to an accident resulting in the disruption of maximum local output. However, power generator failures exceeded the assumed accident level, leading to the large blackout throughout Hokkaido. Internationally, blackouts caused by such large-scale natural disasters are usually assessed as "inevitable." If any blackout were to be avoided even in such large-scale disaster, stable power supply assessment approaches would have to be reformed. As the blackout spread throughout Hokkaido in the early morning on 6 September, power supply restoration operations started around noon. As of 0.00 a.m. on 8 September, the power restoration rate stood at 89%. By the morning of 9 September, power supply had been restored for the whole of Hokkaido, excluding the physically damaged areas.

In restoring power supply, Hokkaido Electric Power first operated hydropower plants that can respond to power supply orders and autonomously operate and gradually restored operation at fossil-fired power plants.

(2) Tight supply-demand balance and relevant countermeasures

After power supply capacity was restored gradually, capacity as of 8 September was still limited to 3.59 GW against 3.83 GW in peak demand on 5 September before the earthquake, leading to power saving requests. Although no more widespread blackout came before the preparation of this report (15 October 2018), the generation reserve capacity rate was still limited to less than 3% on 14 and 15 September, indicating severe conditions.

At the Tomato-Atsuma power station, Unit 1 with capacity at 350 MW was restored within September. Restoration was planned for mid-October for Unit 2 with capacity at 600 MW and in or after November for Unit 4 with 700 MW, indicating potential supply capacity shortages toward winter, when power demand will increase. If such potential lingers toward winter, power saving requests and the installation of additional capacity including emergency power sources may be implemented, as seen in the run-up to the summer after the Great East Japan Earthquake.

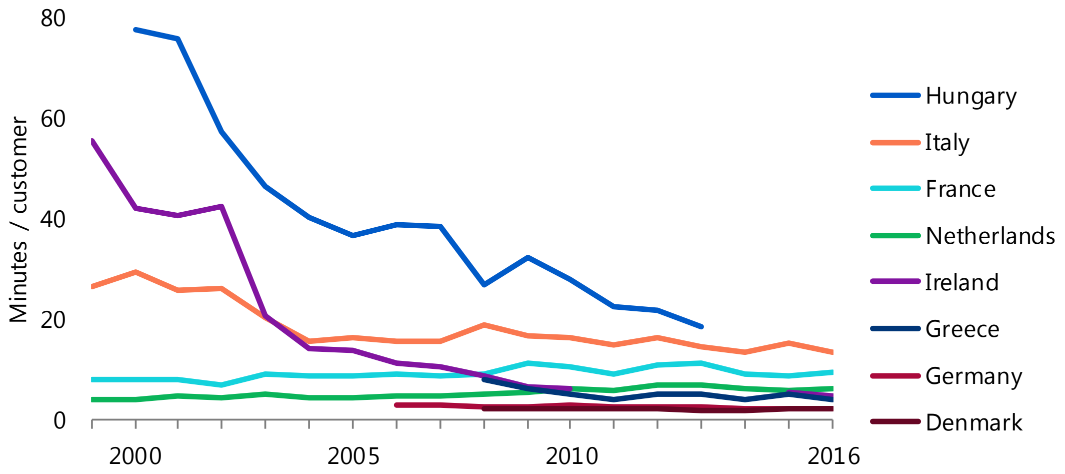
Hokkaido Electric Power has been constructing the Ishikari LNG-fired power station (including Unit 1 planned to start operation in February 2019) to cover for some outdated fossil fuel-fired power generation capacity and is proceeding with a plan to expand the Hokkaido-Honshu interconnection capacity by 300 MW by March 2019. If any of the plans were completed earlier, the company would improve the reliability of its power supply. The earthquake came at a very unfortunate timing for the power utility.

Japan has been introducing power distribution automation systems since the 1980s, resulting in the current situation where outage durations do not differ much from region to region or between urban and rural regions.

Europe

While the provision of information about the quality of electricity supply is limited in Europe, the Council of European Energy Regulators (CEER) occasionally publishes a report on outage durations in member countries. The report indicates that outage durations are shorter for France, Germany, Denmark and the Netherlands in the central part of the European Continent while being longer in Eastern Europe, Italy and Ireland (Figure 6-5). Countries that had earlier been plagued with longer outage durations tended to shorten such durations in the 2000s, narrowing the gap with the others by upgrading power distribution systems. However, power supply quality gaps remain wide between urban and suburban regions. For example, France posted an urban average forced outage duration of 34.6 minutes against the suburban average of 118.4 minutes in 2013, indicating a nearly three-fold gap. While customers have been calling for shortening outage durations through information technology development, few countries have realised high power supply quality on a nationwide basis.

Figure 6-5 | Average outage durations for low-voltage customers in Europe



Note: Planned outage durations are excluded.
Sources: CEER "CEER Benchmarking Report 5.2 on the Continuity of Electricity Supply" February 2015 and "CEER Benchmarking Report 6.1 - Continuity of Electricity and Gas supply" 26 July 2018

New factors for supply disruptions

Power supply disruptions have so far been caused mainly by natural disasters and power grid accidents. However, new risks for short outage durations have been pointed out due to power market deregulation and climate change countermeasures including the promotion of renewable energy power generation. The new risks are (1) the growing dependence on a specific energy source, (2) the duck curve of net load due to the expansion of solar PV power generation, (3) the shutdown of power plants based on economic efficiency and (4) cyberattacks.

Growing dependence on a specific energy source

In the United States that heavily depended on coal-fired power generation, a rising number of regions have increased their dependence on natural gas-fired power generation in line with natural gas price drops. As natural gas is pipelined, power supply disruptions can be caused not only by the forced shutdown of power plants under extreme weather conditions but also by natural gas supply disruptions. When a winter storm forced natural gas-fired power generation capacity to be shut down in the U.S. Northeast in January 2018, in fact, some capacity was suspended because of natural gas supply facility failures or pipeline destruction. As dependence on a specific energy source increases, risks peculiar to the energy source could arise and inflate the possible damages. In response to the growing dependence on natural gas, the United States has begun to develop new risk assessment approaches and enhance countermeasures.

Duck curve of net load due to the expansion of solar PV power generation

California and Japan, where solar PV power generation has expanded, have seen growth of the so-called duck curve phenomenon in which net load peaks twice a day. As electricity demand increases steeply from the daytime to the evening, supply capacity is required to respond to such steep increase in output. However, such supply capacity is limited to pumped storage and natural gas-fired power plants, indicating that shortages in quick power generation capacity could affect the supply-demand balance. Californian independent system operators are preparing for risks by verifying whether power supply capacity could respond to hourly and three-hour output changes based on past data. Power supply reliability assessment has so far focused on whether enough quantitative supply capacity is secured to respond to the maximum anticipated demand. From now on, however, consideration would also have to be given to supply flexibility, a measure representing quality.

Shutdown of power plants based on economic efficiency

Economic efficiency for a specific power source could deteriorate, forcing massive power generation capacity to be closed in a short period of time. As natural gas prices declined in the United States, coal-fired power generation capacity totalling 55.26 GW was closed between 2014 and 2017. In a questionnaire survey of transmission system operators by the European Network of Transmission System Operators for Electricity (ENTSO-E) for its annual medium-term assessment of power supply adequacy, respondents answered that fossil fuel-fired power plants could be closed toward 2020 and 2025 due to the absence of a power capacity market or problems related to market deterioration (including the so-called missing money problem) in 45% of European countries. In the whole of Europe, the loss of fossil fuel-fired power generation capacity could total 25.30 GW in 2020 and 29.43 GW in 2025. The risk of such losses is recognised in France, Germany and Poland. Once power generators are separated from power transmitters and distributors, it will be difficult for transmission system operators and power supply reliability assessment bodies to identify such risks. How to collect the relevant information would be a challenge.

Cyberattacks

In addition, cyberattacks could force power generation capacity to suspend operation. In the Ukraine, cyberattacks caused blackouts in December 2015 and December 2016. Attackers hacked into grid control systems to directly control power supply, leading to power outages. Private circuits for linking grid control-related facilities, as seen in Japan, are less vulnerable to cyberattacks than public circuits. If the power supply share expands for virtual power plant (VPP) capacity combining small distributed plants through aggregators, however, cyberattacks on VPP supply and demand management systems could affect overall supply and demand management.

6.3 Conclusion

We have so far discussed the risks, causes and impacts of oil and electricity supply disruptions. How should we summarise the characteristics of and countermeasures for supply disruptions for two totally different forms of energies? Here, we would like to compare oil and electricity supply disruptions in terms of "geographical spread of impacts," "demand substitution" and "responses to supply disruptions" (Table 6-3). Attention should be paid to the point that the assessments are relative between oil and electricity supply disruptions.

Table 6-3 | Features of oil and electricity supply disruptions

	Oil	Electricity
Geographical spread of impacts	Wider	Limited
Demand substitution	More elastic	Less elastic
Responses to supply disruptions	Diversification of import sources and routes Geographical distribution of domestic facilities Greater redundancy of domestic supply network Support for stabilising oil producing economies Stockpiling	Diversification of power generation fuels Geographical distribution of power generation facilities Greater redundancy of transmission and distribution networks Reserve power generation capacity

Note: The assessments of the geographical spread of impacts and demand substitution represent the relative relationship between oil and electricity.

The geographical spread of supply disruptions' impacts is wider for oil and limited for electricity. Oil supply disruptions occur due to various factors regarding oil producing countries and international transportation routes. In such case, their impacts spread throughout the world. In a time where oil futures markets have been particularly well developed, the impacts will spread to every corner of the world economy in a short period of time in the form of soaring international prices rather than physical limits on supply. Given that electricity is provided through a closed system for each country or region, the impact of an electricity supply disruption is often limited to the relevant country or region. In developed countries where the automation of transmission and distribution systems has made progress, any troubled networks are automatically and quickly separated to limit the geographical spread of impacts.

The short-term demand substitution responding to supply disruptions is more elastic for oil and less elastic for electricity. Responses to an energy supply disruption include switching to another energy source. Electrical equipment cannot be powered by any other energy source than electricity. Motors, air conditioners and lamps cannot work without electricity, indicating that substitution for electricity demand is less elastic. Although substitution for demand for oil as vehicle fuel is less elastic, non-oil energy sources can be used for boilers and power generators. Plug-in hybrid vehicles can substitute electricity for oil.

Lastly, many responses to oil and electricity supply disruptions are common, represented by such keywords as diversification, greater redundancy and distribution. For oil, the diversification of import sources and routes is effective for dispersing risks. Domestic oil supply networks can enhance their resilience to supply disruptions through the geographical distribution of oil refineries and depots and greater network redundancy. For electricity, the diversification of power generation fuels, the geographical distribution of power plants and the greater redundancy of transmission and distribution networks can reduce supply disruption risks and enhance their resilience to disruptions.

However, the diversification and greater redundancy of infrastructure mean increased costs, indicating that it would be difficult but necessary to balance enhanced security with economic rationality. In a deregulated market, the companies' attempt to maximise profits occasionally threatens the stability of supply. For example, such attempt leads to high dependence on specific oil import sources or specific power generation sources. Some regulations may be required to maintain the diversity but may threaten to distort market competition, indicating a dilemma between enhanced security and economic rationality again.

Making a difference from electricity, oil can be stockpiled mainly for responding to emergencies, although stockpiling methods and requirements differ from country to country. Furthermore, the member countries of the International Energy Agency (IEA) have established a system for their cooperation in dealing with emergencies. Oil reserves, though having been released rarely, contributed to maintaining smooth supply in response to supply disruptions caused by the Gulf War (1991), the Hurricane Katrina disaster (2005) and the Great East Japan Earthquake (2011). Japan has developed arrangements for the cooperation of the oil companies and the core and base gas stations to maintain oil supply, in the face of disasters.

Regarding oil, it is also important to support the economic stabilisation of oil producing countries. As indicated by past developments, instability in oil producing countries is one of the factors that induce oil supply disruptions. The economic stabilisation could reduce social unrest, contributing to stabilising oil producing countries and their oil supply.

As for electricity, there is no equivalent to oil stockpiling because current technologies cannot economically store electricity on a large scale for a long period of time. Instead of stockpiles, in response to electricity supply disruptions, reserve power generation capacity should be considered. For example, if a power plant is forced to suspend operation due to a failure or if solar PV power generation declines rapidly on a weather change, reserve power plants prepared for such event could be promptly put into operation to maintain electricity supply capacity.

Unlike oil reserves, however, enough reserve power generation capacity for responding to electricity supply disruptions has not been institutionally secured. Before the power market deregulations of Japan, European countries and other developed countries, vertically integrated regional monopolistic utilities had voluntarily maintained more reserve power generation capacity than required by the regulators. However, retail power market deregulation has unleashed fierce competition and, in such environment, it is difficult for any utility to voluntarily maintain enough reserve power generation capacity. An institutional system is required to secure enough reserve capacity and such system should provide for adequate considerations for securing reserve capacity.

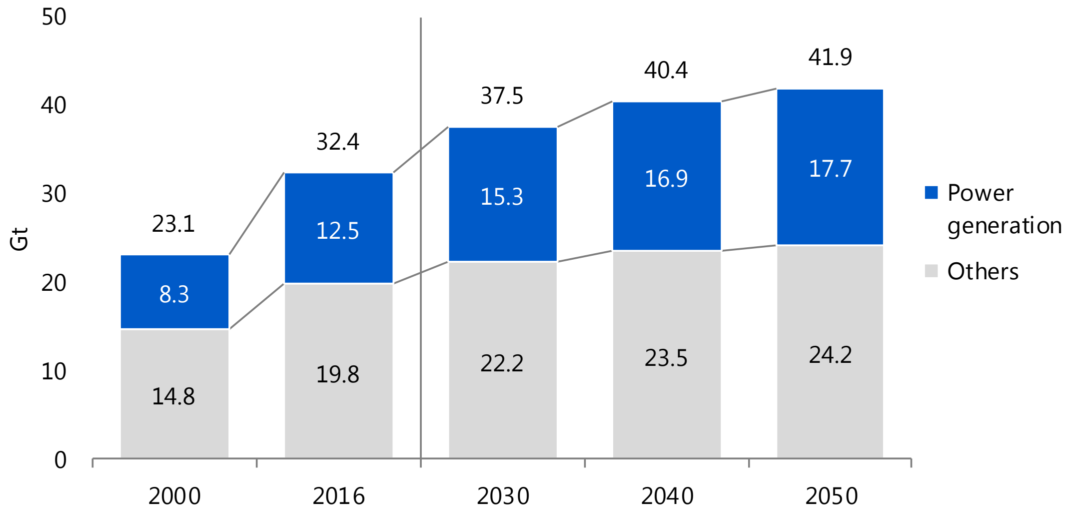
The duck curve of net load due to the expansion of solar PV power generation, combined with the diversification of power generators do require a complex grid management. On the other hand, technological innovations such as the improvement of supply and demand prediction accuracy through artificial intelligence (AI), the management of demand using Internet of Things (IoT) and the adjustment of supply and demand using batteries for electric vehicles are making it possible to implement power supply stabilisation measures that had been unimaginable not so long ago. With promoting strong climate change countermeasures and progressing switch to electricity from other energy sources for digitalisation, it will grow more important to prepare for electricity supply disruptions. While various electricity supply stabilisation measures have been implemented or considered in countries that have deregulated electricity markets and expanded renewable energy, it is essential to establish appropriate security systems in electricity markets, including measures against cyberattacks that are becoming a real threat.

7. Impacts of banning the construction of new coal-fired power plants

7.1 Movements against coal-fired power generation

Global energy-related CO_2 emissions will increase from 32 Gt in 2016 to 42 Gt in 2050 in the Reference Scenario. Direct emissions from the power generation sector at 5.2 Gt will account for the majority of the increase of 9.6 Gt. Against such backdrop, the low-carbonisation of the power generation sector must become a core climate change countermeasure rivalling energy efficiency improvement in the final energy consumption sector.

Figure 7-1 | Global direct energy-related CO_2 emissions [Reference Scenario]



Low-carbonisation technologies expected in the power generation sector are roughly divided into three categories – the improvement of fossil fuel-fired power generation efficiency, the adoption of low-carbon energy sources and carbon capture and storage (CCS). Regarding the adoption of low-carbon energy sources, some increasingly unforgiving views have been presented in recent years against burning coal, which features the most carbon emissions per unit of electricity generated. Examples of such views are announcements by the World Bank and others of restricting loans to support the construction of new coal-fired power plants (Table 7-1). The statements represent a financial blockade to discourage the construction of new coal-fired power plants in developing countries that are less capable of raising funds on their own. Under the slogan of environmental, social and governance (ESG) investment or divestment, some private sector moves have been seen to refrain or withdraw from investing and/or providing loans for coal-fired power plants.

Table 7-1 | Growing movement for a coal phase-out

2013	[World Bank] Announcing a policy of terminating financial support for the construction of new coal-fired power plants in cases other than rare ones
2015	[G20 finance ministers and central bank governors meeting] Pointing out the risk of low-carbonisation exerting financial impacts on the financial sector. Establishing the Task Force on Climate-related Financial Disclosures (TCFD). [OECD] Restricting official support for less efficient coal-fired power generation in official export credit arrangements
2017	[Netherlands] A coalition government agreement calls for shutting down five coal-fired power plants by 2030. The United Kingdom and Canada take the initiative in launching the Powering Past Coal Alliance (PPCA) [TCFD] Proposing recommendable information disclosure regarding risks and opportunities accompanying a transition to a low-carbon society
2018	[United Kingdom] A final document for phasing out coal-fired power generation by 2025 [Germany] A coalition government agreement calls for resuming considering the phasing out coal-fired power generation.
2019	[OECD] Planning to revise rules for official export credit arrangements

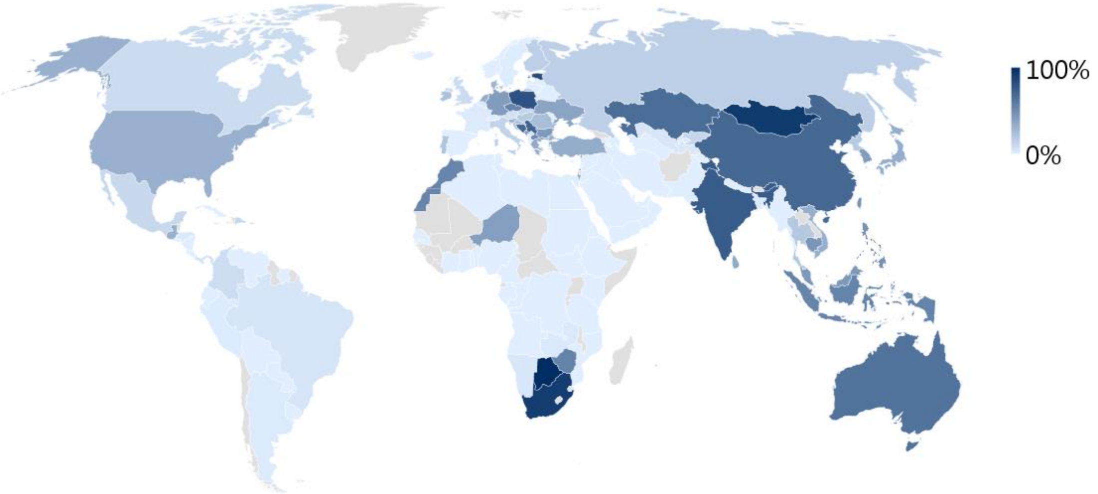
7.2 Regional characteristics and backgrounds on coal use

If top priority is given to the reduction of CO_2 emissions, there is no room for opposing such anti-coal policy. If so, however, people may be criticised for living in cold regions and should fail to receive loans for detached houses for the reason of massive CO_2 emissions. It is no doubt that climate change countermeasures represent key challenges for human beings, forming one of the pillars of the United Nations' 17 sustainable development goals (SDGs). CO_2 emissions, however, should not be viewed as the only standard for setting energy use policies. This is because energy use policies depend on a variety of factors such as, local resource endowment conditions, historical backgrounds, non-energy challenges as well as energy problems.

Coal is the world's largest power source covering 38% of global power generation (2016). However, coal use intensity differs by region (Figure 7-2). Among economies that use coal for generating more than a certain volume of electricity[28], South Africa posts the highest power generation mix share for coal, followed by Poland. A total of 13 economies from regions other than the Americas show greater coal shares than the global average. Naturally, most of them are either rich with coal resources, or poorer with non-coal energy resources than with coal resources or generally poor with energy resources[29] (Table 7-2). In contrast, "coal phase-out economies[30]" are mostly richer with non-coal energy resources than with coal resources.

[28] More than 50 TWh, almost equivalent to power generation in Singapore.
[29] Some economies have their respective unique reasons for high coal consumption, including historical policy support for the coal (lignite) industry in Germany and rapid electricity demand growth in Malaysia that had been rich with natural gas and oil resources.
[30] "Coal phase-out economies" here are defined by Greenpeace "Global Shift" as those that have already abolished or have plans to abolish all coal-fired power plants and those that have almost

Figure 7-2 | Coal's share of the power generation mix [2016]



Source: IEA "World Energy Balances"

Table 7-2 | Resource endowment conditions in economies with high power generation mix shares for coal and in "coal phase-out" economies

		Coal resources		
		←Poorer		Richer→
Other energy resources	↑ Richer	Malaysia, Netherlands, Albania, and Ghana		Kazakhstan, Australia, Indonesia, and Canada
		Philippines, Australia, Finland, France, Sweden, United Kingdom, El Salvador, and Latvia	India	South Africa, China, Czech Republic, and New Zealand
		Belgium and Portugal		
	Poorer ↓	Chinese Taipei and Korea	Germany and Belarus	Poland

Note: Economies with high power generation mix shares for coal are in red ink and "coal phaseout economies" in black ink. Non-coal energy sources include non-fossil resources. Resource endowment conditions represent self-sufficiency rates in 2014 before growth in arguments against coal-fired power generation.

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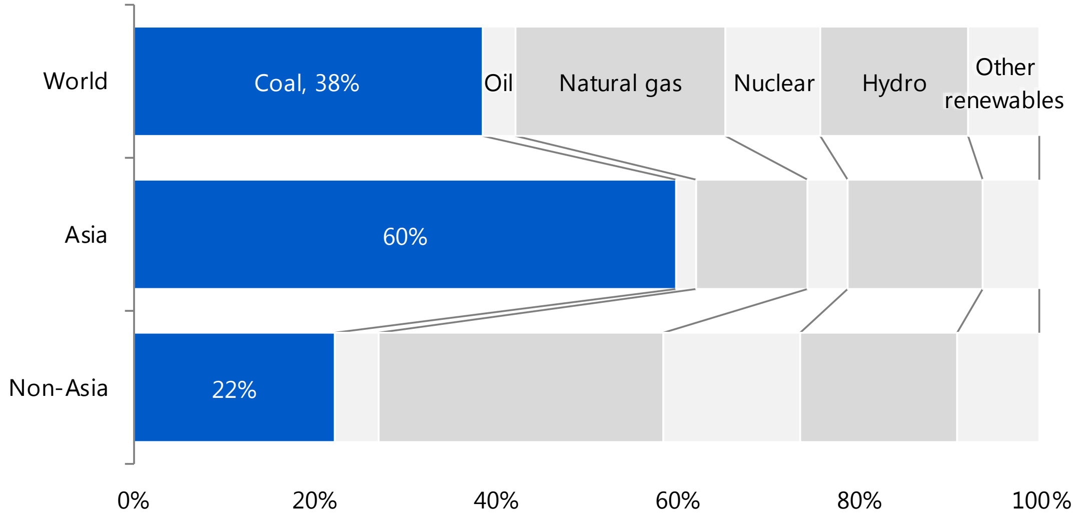
phased out coal-fired power plants or ceased to construct new such plants.

Among regions, Asia depends heavily on coal-fired power generation. Coal's share of the power generation mix in Asia is 60%, nearly three times as high as in non-Asian regions where natural gas is the largest power source (Figure 7-3).

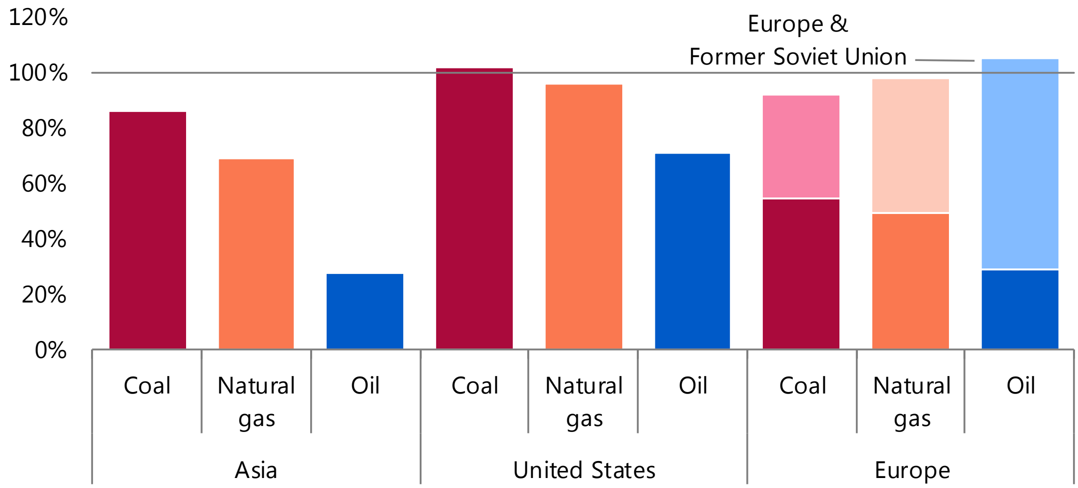
Figure 7-3 | Power generation mix [2016]



Source: IEA "World Energy Balances"

Asia is generally poor with natural gas or oil resources. A comparison of Asia with Europe and the United States indicates such feature for Asia more clearly (Figure 7-4). Europe's energy self-sufficiency rate is almost equal to or less than the Asian rate because of its energy demand and resources depletion. If consideration is given to the former Soviet Union that has had historically close relations with Europe in terms of energy supply, however, Europe's situation looks different from Asia's.

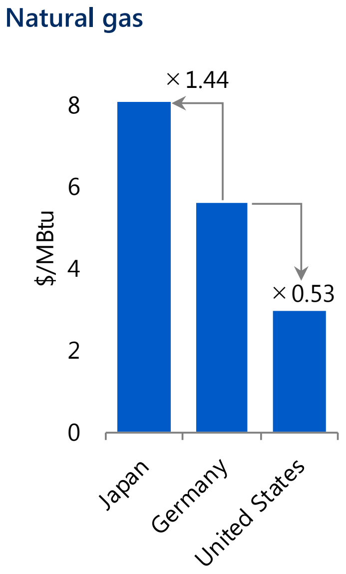
Figure 7-4 | Fossil fuel self-sufficiency rate [2016]

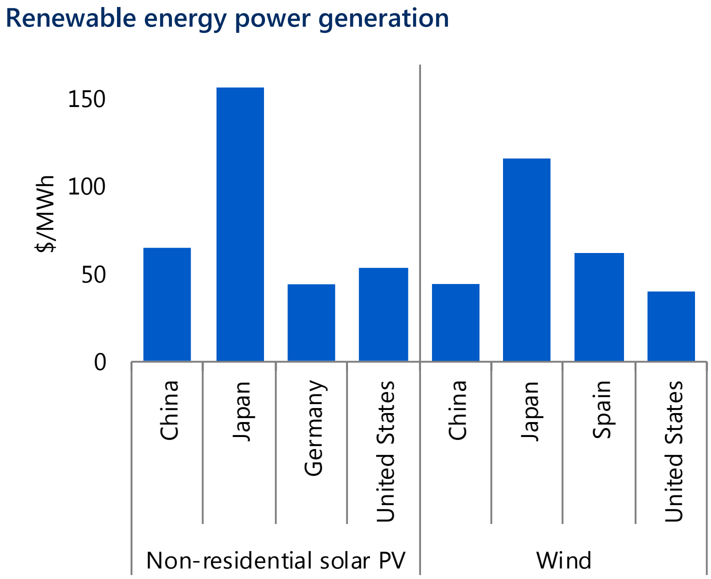


Source: IEA "World Energy Balances"

The historical relations are significant particularly for natural gas that is used in place of coal for power generation. Beginning in the 1970s, pipeline networks were developed for transporting abundant natural gas from the former Soviet Union to the then communist countries in Eastern Europe. The network was developed for promoting the international division of labour among the then communist countries and for enhancing the Soviet Union's political control of Eastern Europe. These international pipelines were later combined with European countries' domestic pipelines to pave the way for Europe to easily access and use relatively cheap natural gas[31]. Yet, natural gas prices in Germany, where Russian pipeline natural gas supply is dominant, are higher than in the United States where prices have plunged under the shale revolution (Figure 7-5). Natural gas prices in Japan that depends mainly on LNG for its natural gas supply are, however, far higher. One reason for Asia's heavier dependence on coal than on natural gas is the absence of any regionwide source for cheap, abundant natural gas supply, differentiating Asia from Europe as well as the United States where coal-fired power generation has lost ground to natural gas-fired power generation for economic reasons.

Figure 7-5 | Asian, European and U.S. energy prices





Note: Natural gas prices are the LNG import CIF price for Japan, the import CIF price for Germany and the Henry Hub spot price for the United States in 2017. Renewable energy power generation prices represent the levelised costs of electricity (LCOE). Non-residential solar PV data in China and the United States are for 2017 and those in Japan and Germany for 2016. Wind data in China and Spain are for 2017 and those in Japan and the United States are for 2016.
Sources: BP "BP Statistical Review of World Energy 2018" [Natural gas], IEEJ estimates [Renewable energy power generation]

Economic efficiency differs by region and not only for natural gas. Renewable energy power generation costs have declined on technological innovation in Europe, including some

[31] Meanwhile, Europe's heavy dependence on Russia resulting from such natural gas supply is seen as problematic.

countries where fossil fuel-fired power generation has lost ground to renewable energy power generation due to electricity wholesale systems. Among Asian countries, China has taken a strong policy to reduce renewable power generation costs. In Japan, however, solar PV power generation costs have remained high despite a massive expansion of solar PV. Contrary to Europe, Asia failed to develop an international grid network and faces a disadvantage that limits the use of cheaper measures to include massive electricity from intermittent renewable energy power sources into its grid networks.

The extent of the barriers to replacing coal with natural gas or renewable energy differs widely from region to region. The fact that coal is the largest power source in Asia reflects regional conditions. Difficulties in reducing the dependence on coal should not be considered in Asia in the same way as in Europe or the United States.

7.3 Impacts of banning the construction of new coal-fired power plants

Case setting

There are many problems that must be overcome before any major energy transition. We here recognise but shelve such problems for now and simulate a hypothetical case in which all new coal-fired power plants would be banned from being constructed from 2020 (No New Coal-fired Power Plant Case). Through the simulation, we assess the impacts of the coal-fired power generation phase-out that has been from time to time naively talked.

Figure 7-6 | Global installed coal-fired power generation capacity [Reference Scenario]

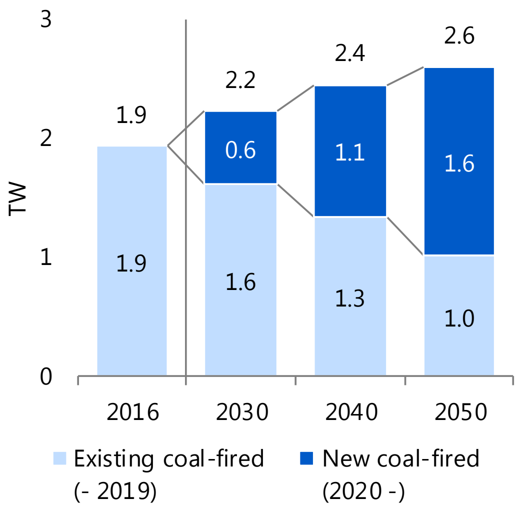
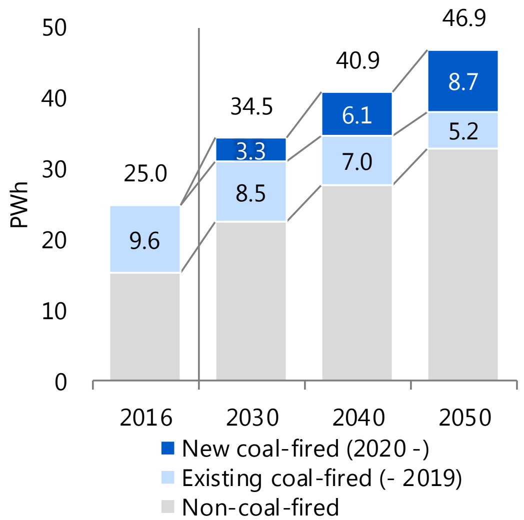


Figure 7-7 | Global power generation [Reference Scenario]

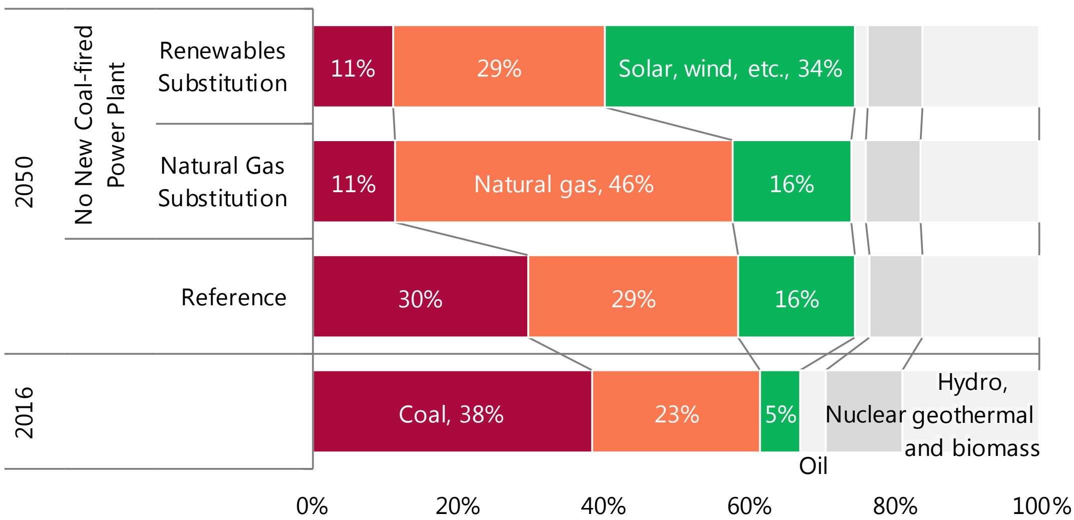


Electricity from the planned new coal-fired power generation capacity would be covered in two possible ways – by natural gas-fired power generation or by solar PV / wind power generation[32].

Power generation mix

In the Reference Scenario, coal will account for 30% of global power generation in 2050 (Figure 7-8). If new coal-fired power plants are banned from being constructed from 2020, however, coal's share of the power generation mix will decline to 11%, with non-coal-fired power generation capacity replacing 1.6 TW in planned new coal-fired power generation capacity in 2050. However, such energy transition will widely differ from region to region.

Figure 7-8 | Global power generation mix

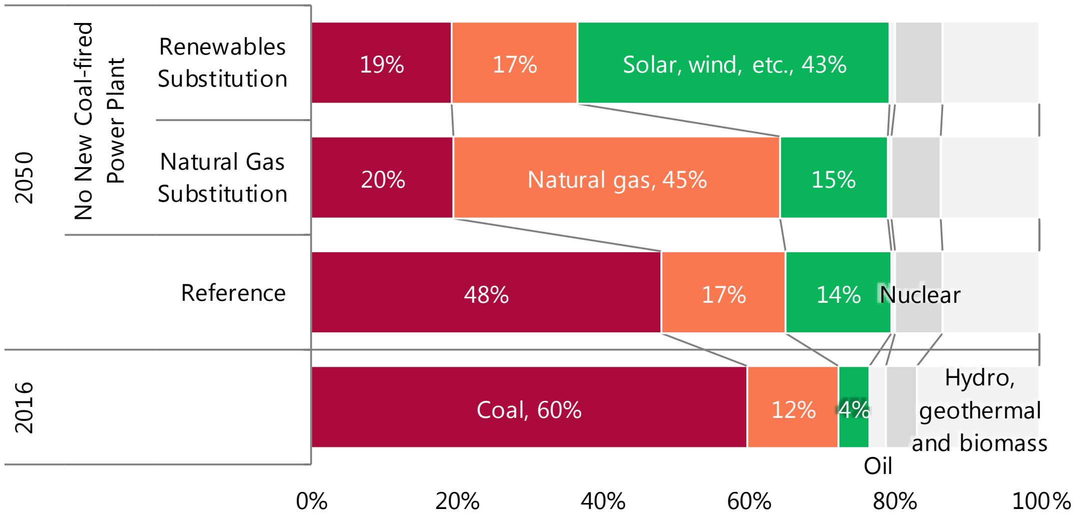


Note: Electricity demand changes accompanying price changes are taken into consideration.

In Asia, coal's share of the power generation mix in 2050 in the Reference Scenario will stand at around 50%, about 80% of the present level. If new coal-fired power plants are banned from being constructed from 2020, however, the coal share will plunge to 20% (Figure 7-9). The gap of 30 percentage points or 6.9 PWh will be covered by natural gas or solar PV and wind. If natural gas covers the gap, coal and natural gas will exchange their shares in the Reference Scenario, making a great transition. If solar PV and wind cover the gap, solar PV, wind, etc. will account for 43% of total power generation. It will be ideal but more difficult for solar PV and wind to substitute for new coal-fired power generation capacity.

32 Solar PV capacity and wind capacity are prorated according to their respective shares of the power generation mix in each region in the Reference Scenario for descriptive purposes.

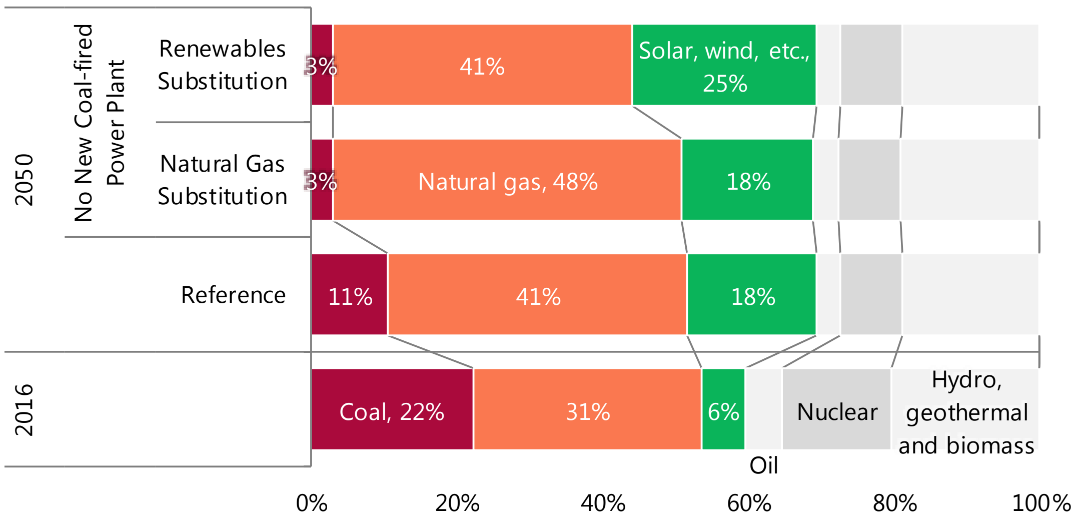
Figure 7-9 | Asian power generation mix



Note: Electricity demand changes accompanying price changes are taken into consideration.

In non-Asia regions, coal's share of the power generation mix will be limited to 11% even in the Reference Scenario. Even if new coal-fired power plants are banned, the share will fall only by 8 percentage points (Figure 7-10). Any change emerging from the ban will be more limited than in Asia. Even if solar PV and wind power generation capacity substitutes for new coal-fired power plant capacity, the solar PV, wind, etc. share will be restricted to 25%, with natural gas remaining the largest electricity source. This share slips below 30% in the Advanced Technologies Scenario.

Figure 7-10 | Non-Asia power generation mix



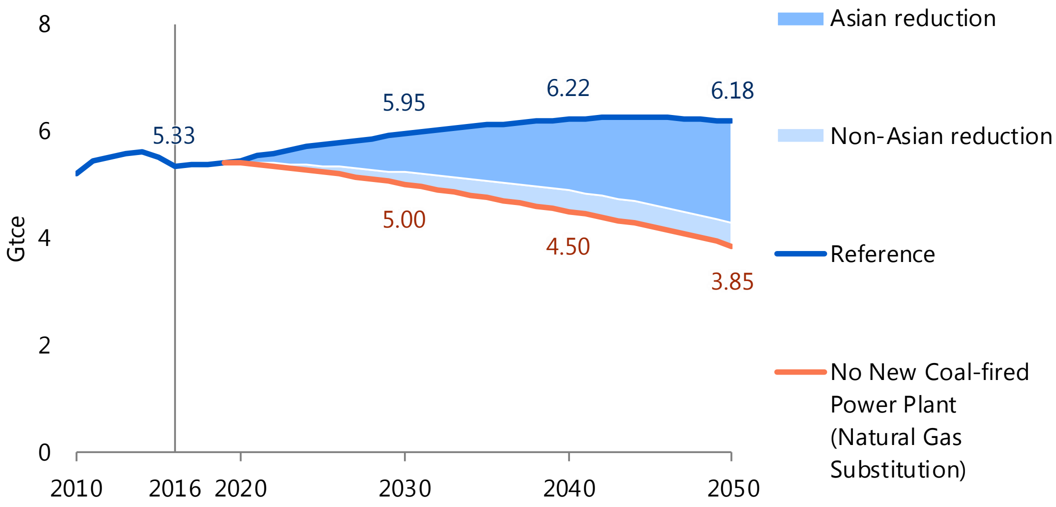
Note: Electricity demand changes accompanying price changes are taken into consideration.

Effects of banning new coal-fired power plants

Coal consumption decline

Coal consumption of which the power generation sector now accounts for as much as 62% will dramatically change due to such power generation mix transition. While primary coal consumption is projected to increase by 0.8 billion tonnes of coal equivalent (Gtce[33]) from the present level to 6.2 Gtce in 2050 in the Reference Scenario, the banning of new coal-fired power plants will reduce primary coal consumption to 3.8 Gtce or to slightly more than 70% of the present level (Figure 7-11). From the Reference Scenario, primary coal consumption in 2050 will decrease by 2.3 Gtce, comparable to the current production level in China, the world's largest coal producing and consuming country. The decline will concentrate in Asia.

Figure 7-11 | Global primary coal consumption



Note: The No New Coal-fired Power Plant (Renewables Substitution) Case is almost similar to the No New Coal-fired Power Plant (Natural Gas Substitution) Case.

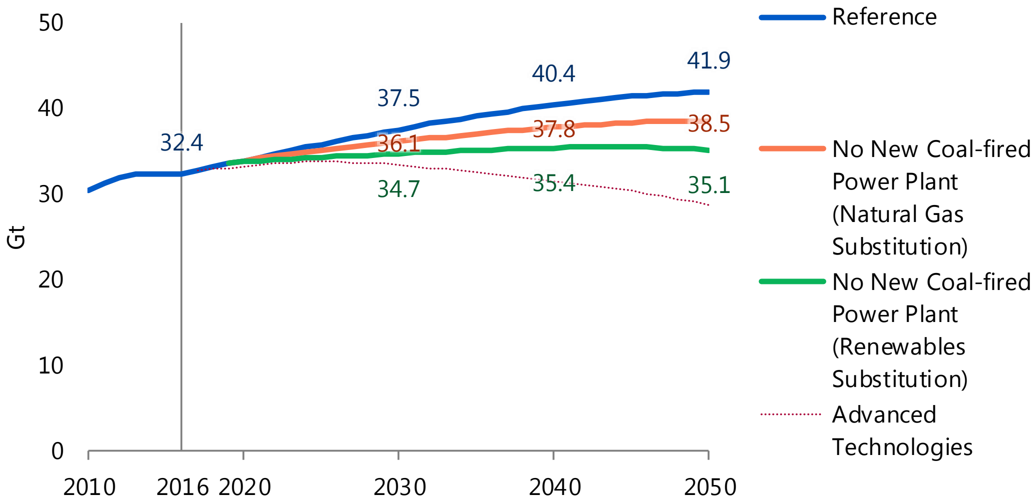
CO_2 emissions reduction

Reducing the consumption of coal that features the highest carbon emission intensity among energy sources will result in substantial cuts in CO_2 emissions. While global energy-related CO_2 emissions are projected to increase to 41.9 Gt in 2050 in the Reference Scenario, the substitution of natural gas-fired power generation for new coal-fired plants will cut the emissions by 3.5 Gt and the substitution of solar PV and wind power generation for coal-fired plants by 6.8 Gt, comparable to the combined current emissions in the United States and India, the world's second and third largest CO_2 emitters (Figure 7-12). Nevertheless, CO_2 emissions in the Renewables Substitution Case will stand at 35.1 Gt, far above the 28.7 Gt of the Advanced Technologies Scenario and the present level of 32.4 Gt. While phasing out coal has attracted attention as a major CO_2 emission reduction measure, it will not resolve the climate change

33 1 tce = 0.7 toe

problem even when solar PV and wind power generation are substituting for new coal-fired power generation plants.

Figure 7-12 | Global energy-related CO_2 emissions



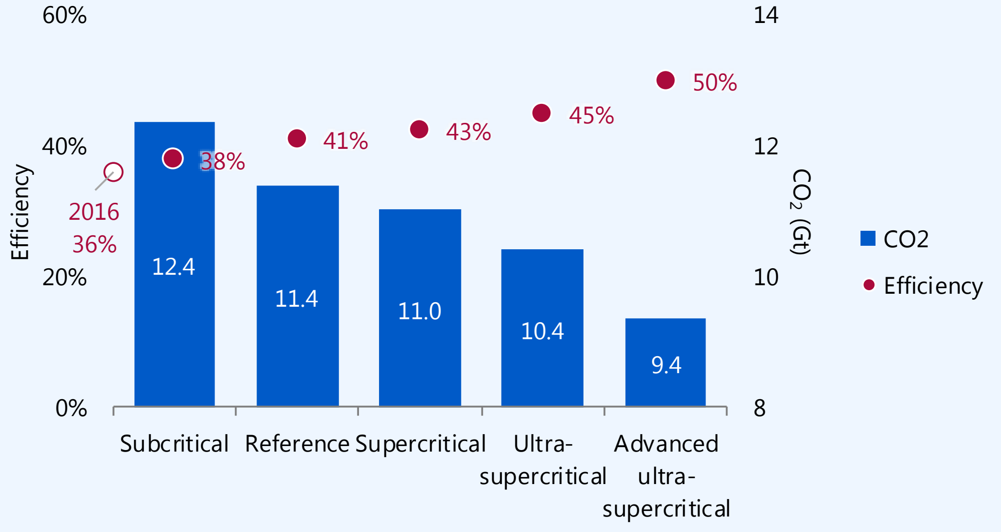
Box 7-1 | Coal-fired power generation efficiency and CO_2 emissions

A ban on investments and loans for new coal-fired power plant construction is designed to discourage construction. However, some are concerned that power generators facing fundraising difficulties could choose to construct cheaper, less efficient coal-fired power plants emitting more CO_2, instead of switching from coal-fired power generation to non-coal-fired power generation. In fact, we frequently see companies making responses that do not meet the original policy objectives.

In the Reference Scenario, coal-fired power generation's average efficiency will increase from 36%[34] at present to 41% in 2050, with direct CO_2 emissions from coal-fired power generation totalling 11.4 Gt (Figure 7-13). If the efficiency is limited to the subcritical coal-fired power plant level of 38%, however, CO_2 emissions will increase by 1.0 Gt from the Reference Scenario. If the efficiency is raised to the ultra-super critical coal-fired power plant level of 45%, emissions will decline by 1.0 Gt. Given that the world seems to have no choice but to depend on coal-fired power generation, it will have to consider how to use coal while minimising its environmental load.

[34] The current level slips even below the subcritical coal-fired power plant level of 38%, resulting from low hardware performance and inadequate operation and management.

Figure 7-13 | Global coal-fired power generation efficiency and direct CO_2 emissions

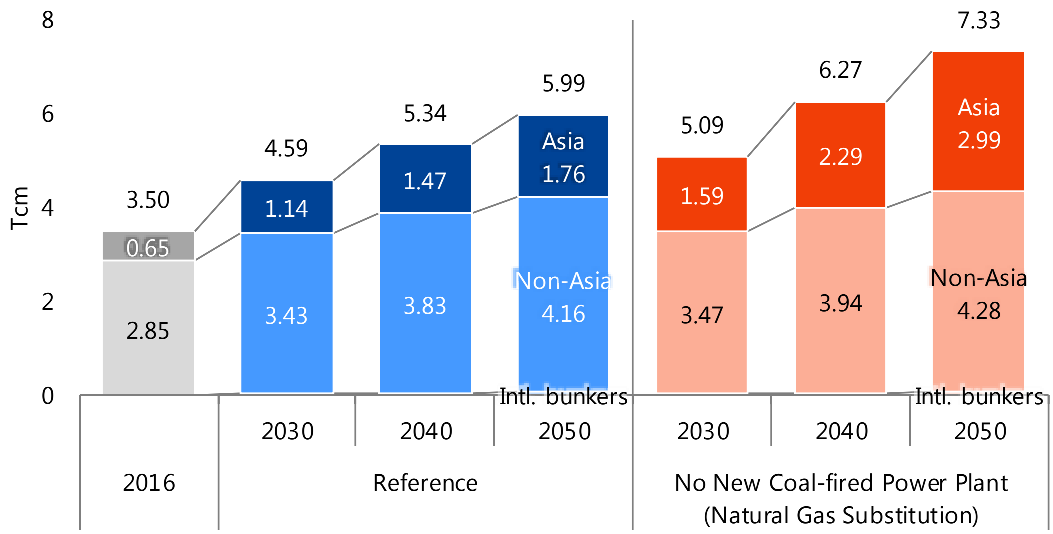


Inevitable side effects – Natural Gas Substitution Case

Growing natural gas consumption

If natural gas-fired power plants are built in place of new coal-fired power plants, natural gas will replace oil as the world's largest energy source around 2040 and global primary natural gas consumption will reach 7.3 trillion m³ (Tcm) in 2050 (Figure 7-14). The increase of 1.3 Tcm from the Reference Scenario is enormous, being equivalent to the combined current production in the United States and Russia (accounting for 38% of global production).

Figure 7-14 | Global primary natural gas consumption



The projected consumption reflects the downward pressure of the below-mentioned natural gas price hikes on consumption. Without any price hikes, consumption in 2050 will reach 7.8 Tcm, with cumulative consumption between 2017 and 2050 totalling 196 Tcm. The cumulative consumption exceeds the proven natural gas reserves at 192 Tcm at the end of 2016, indicating that resources available for production with present technologies and efficiency could fail to meet demand. Such resources constraint will be severe particularly in Asia.

Natural gas production required to rapidly increase

To meet dramatically growing natural gas consumption, the world will have to develop all resources available including deep-water and Arctic resources that are technically difficult to reach. Shale gas development, which is now being implemented mainly in North America, will have to be done in the former Soviet Union, China, South America, Africa and other regions endowed with shale gas resources.

Great constraints on such rapid natural gas development will include shortages of equipment and human resources. Major short to medium-term challenges will be whether enough gas drilling rigs could be secured, whether materials could be procured smoothly for constructing production and shipment facilities and whether engineers and other workers could be sufficiently secured for development and production. Given that aggressive gas development will be required in regions where gas development is more difficult, it could be problematic to secure enough equipment and human resources.

To develop shale gas in regions other than North America, enough geological data will have to be accumulated and oil / natural gas and services companies with advanced technologies will need to be mobilised. At present and in many countries, however, such geological data have yet to be gathered and companies with sufficient shale gas development know-how also have yet to be skilled and prepared for such large-scale developments.

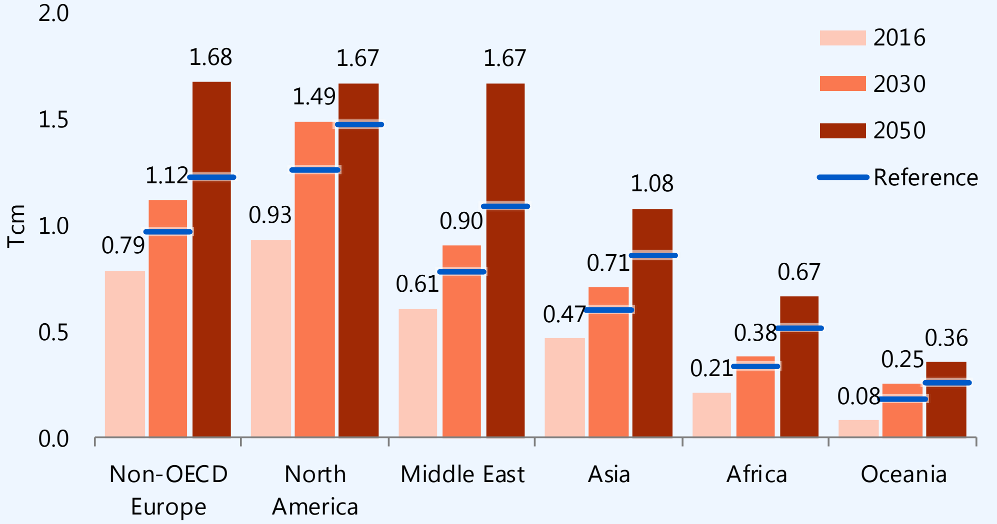
Another constraint will be Western countries’ economic sanctions on gas producing countries. Economic sanctions are imposed on Russia and Iran that hold the key to expanding global natural gas production, making it impossible for European and U.S. companies with advanced natural gas development technologies and capacity to invest in these countries. If economic sanctions are retained long with such companies failing to freely participate in gas development in these countries, serious supply shortages may emerge over a medium to long term.

Box 7-2 | Selected regions’ natural gas production in No New Coal-fired Power Plant (Natural Gas Substitution) Case

In the No New Coal-fired Power Plant (Natural Gas Substitution) Case, global natural gas production will expand 2.3-fold from 2016 to 2050. Making great contributions to increasing natural gas production will be the Middle East with its abundant reserves and non-OECD Europe including Russia and Central Asia[35] (Figure 7-15).

[35] This projection is based on reserves, present production, gas field development, infrastructure development and other factors, with consideration given to how much each region would have to increase production to meet the rapid demand increase. It does not guarantee that such production expansion will be feasible.

Figure 7-15 | Selected regions' natural gas production [No New Coal-fired Power Plant (Natural Gas Substitution) Case]



In the Middle East, countries with enormous natural gas reserves, including Iran, Qatar and Saudi Arabia, will be expected to further expand production. Iraq and the United Arab Emirates, which have so far given priority to oil developments, will need to proactively develop their natural gas resources.

Like in the Middle East, Russia must substantially increase its natural gas production to meet the massive demand for natural gas needed to replace the coal in neighbouring Eastern Europe, former Soviet republics and China. Russia is considering natural gas development in the Arctic Ocean and Eastern Siberia as well as Western Siberia, currently known as a major gas producing region. It will have to launch a full-fledged shale gas development program as well.

North America has rapidly expanded natural gas production through shale gas development since around 2010 and will have to increase production even more rapidly. Generally, production at shale gas fields depletes rapidly after peaking. In the future, North America will have to expand overall shale gas production even while making up for such depletions. As indicated by gas transportation capacity shortages for existing gas pipelines between inland production areas and coastal zones, a transportation infrastructure constraint could be a barrier to production expansion.

LNG production required to expand

The ban on new coal-fired power plants will lead natural gas consumption to grow most in Asia, while production will expand in the Middle East, non-OECD Europe and North America. Geographical gaps between natural gas production and consumption will thus increase further. It will be inevitable for the world to substantially expand international natural gas trade. Particularly, LNG will play a key role in this regard. LNG demand in 2030 will expand from 520 Mt in the Reference Scenario to 750 Mt in the No New Coal-fired Plant (Natural Gas

Substitution) Case (Figure 7-16). To meet the rapidly expanding demand, global LNG production capacity will have to increase by 490 Mt or equivalent to 1.9 times as much as the capacity in 2016, in 14 years. As is the case with overall natural gas supply, it may be very difficult even for the total combination of oil / gas and engineering companies throughout the world to achieve such a rapid expansion of LNG production capacity expansion within such a short period of time.

The projected LNG demand of 750 Mt for 2030 exceeds the total supply capacity (around 720 Mt) including all future LNG projects seen as relatively feasible at present. To fulfil the gap, less feasible projects will have to be developed to launch commercial production by 2030. Given that LNG projects take more than 10 years to be commercialised, it may be very challenging, if not impossible, to bring such many projects to the commercial production phase by 2030.

Figure 7-16 | Global LNG demand

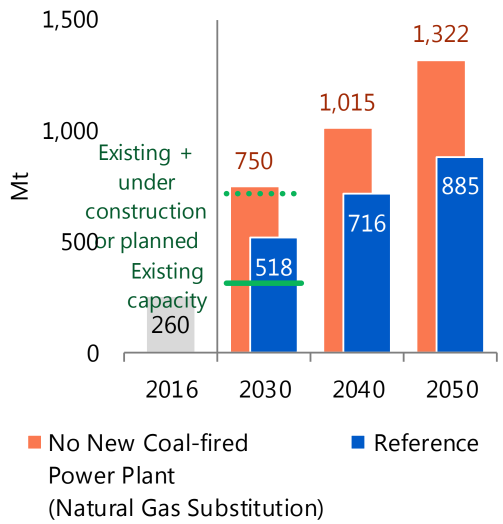
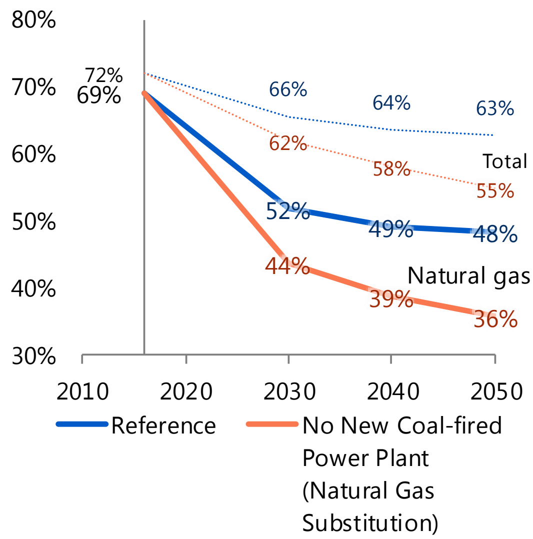


Figure 7-17 | Asian energy self-sufficiency rates



Stable supply measures to address self-sufficiency decline

If the abovementioned global natural gas production expansion and the required LNG supply chain are achieved, Asia would face a new energy security problem. Asia, poor with natural gas resources, would have to depend on imports from non-Asian regions for its natural gas supply expansion. As a result, the natural gas self-sufficiency rate will rapidly fall from 69% at present to 36% in 2050[36] (Figure 7-17).

Increasing natural gas consumption and dependence on natural gas imports will obviously make it even more important for natural gas importing countries to stockpile gas or LNG. However, storing natural gas or LNG costs far much more than storing coal in an open space. As natural gas will replace oil as the most important energy source, the importing countries

[36] The non-Asia natural gas self-sufficiency rate will definitionally increase on the increase in exports to Asia.

will have to develop enough supply arrangements to prevent major energy security risk factors from being generated.

Growing payments for natural gas imports

Natural gas consumption growth will be remarkable in Asia and exert spill-over effects on the rest of the world. We assume that natural gas price hikes through substantial consumption growth will be seen throughout the world[37] (Table 7-3). In the Reference Scenario, the natural gas prices in Japan in 2050 will be about 50% less than oil prices in calorific term and in the United States they will be about 75% less than oil prices. In the No New Coal-fired Power Plant (Natural Gas Substitution) Case, however, the natural gas prices in Japan will be almost equal to oil prices[38] while in the United States that will greatly expand natural gas exports, they will be 30% less than oil prices.

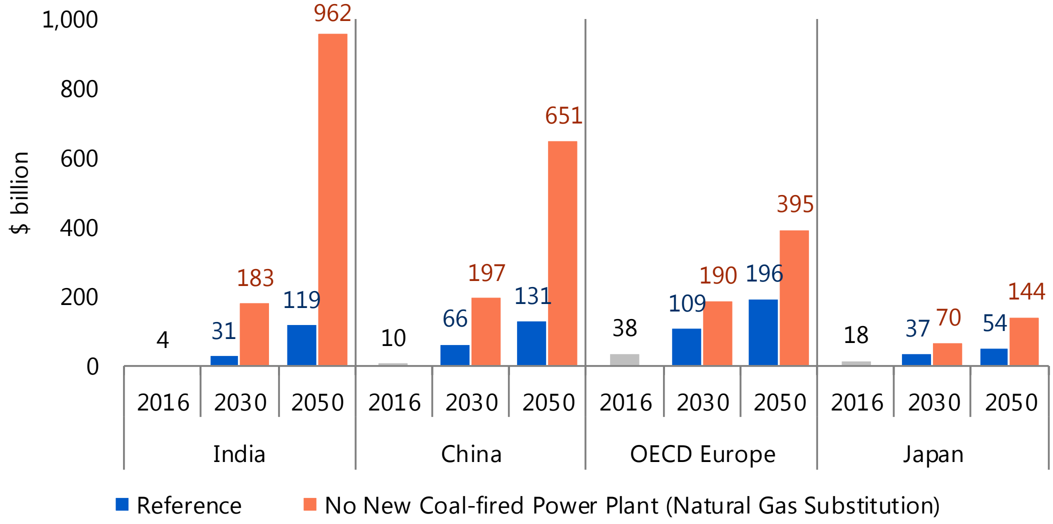
Table 7-3 | Real natural gas prices

			Reference			No New Coal-fired Power Plant (Natural Gas Substitution)		
		2017	2030	2040	2050	2030	2040	2050
Japan	$2017/MBtu	8.1	10.5	10.7	10.8	16.6	18.8	19.5
Europe (UK)	$2017/MBtu	5.8	8.2	8.8	8.9	14.0	16.7	18.0
United States	$2017/MBtu	3.0	4.2	5.0	5.2	10.2	13.3	15.0

Because natural gas price hikes will not be limited to the power generation sector, net natural gas imports in value will increase steeply even in non-Asia regions[39] (Figure 7-18). In OECD Europe, natural gas consumption for power generation even under the ban on new coal-fired power plants in 2050 will post an increase of only 8% from the Reference Scenario, far lower than the global average rise of 60%. Overall primary natural gas consumption in the region will decrease due to the price hikes. Nevertheless, the region's net natural gas imports in value will expand to as much as $400 billion because more natural gas is used for industry and buildings sectors than for the power generation sector in the region where natural gas use has been widespread.

37 While prices will generally increase, LNG trade will expand further in a manner to narrow price gaps between regions.
38 $125/bbl (in 2017 dollars)
39 While natural gas imports in value will increase, coal imports in value will decline on price and volume drops. However, the coal import value is one-10th of the natural gas import value.

Figure 7-18 | Net natural gas imports in value for selected net natural gas importers



In this way, additional natural gas consumption to cover the loss of new coal-fired power plants will induce a great energy security challenge[40].

Inevitable side effects – Renewables Substitution Case

Unprecedented expansion in solar PV and wind power generation

If solar PV and wind power generation covers the loss of new coal-fired power plants, global power generation with solar PV, wind, etc. will be required to expand to 16.1 PWh in 2050 (Figure 7-19). This means that such power generation will have to expand as much as 12-fold from the present level in a little more than 30 years. Low capacity factors for solar PV and wind power generators will also become a heavy burden. Even if power storage and transmission technologies efficient enough to eliminate losses are made fully available throughout the world, global solar PV and wind power generation capacity in 2050 will have to reach at least 10.0 TW – 1.6 times the current combined capacity for fossil fuel-fired, renewable energy and nuclear power generation. Asia will account for 7.2 TW – 2.7 times the current Asian power generation capacity (Figure 7-20).

[40] The IEA defines energy security as "the uninterrupted availability of energy sources at an affordable price," taking not only supply meeting demand but also affordable prices into consideration.

Figure 7-19 | Global power generation with solar PV, wind, etc.

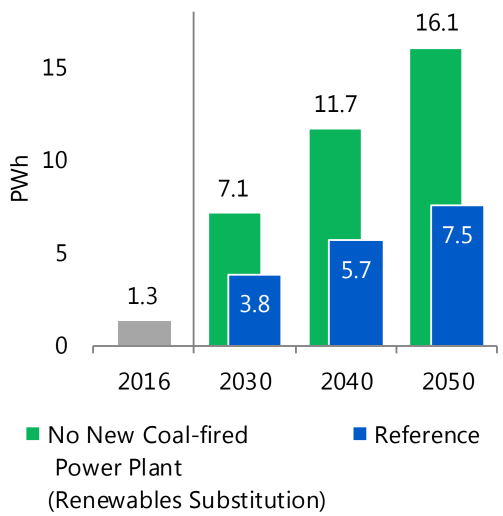
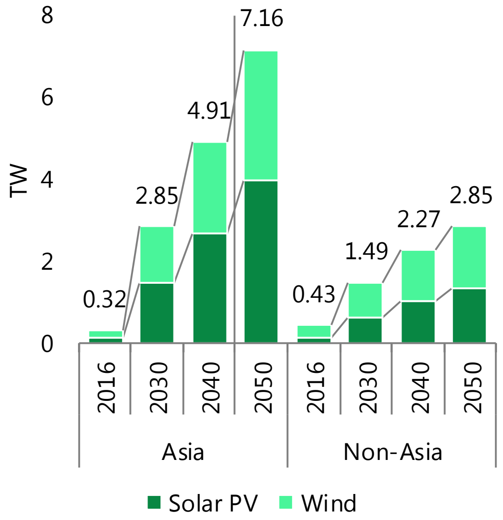


Figure 7-20 | Solar PV / wind power generation capacity [No New Coal-fired Power Plant (Renewables Substitution) Case]

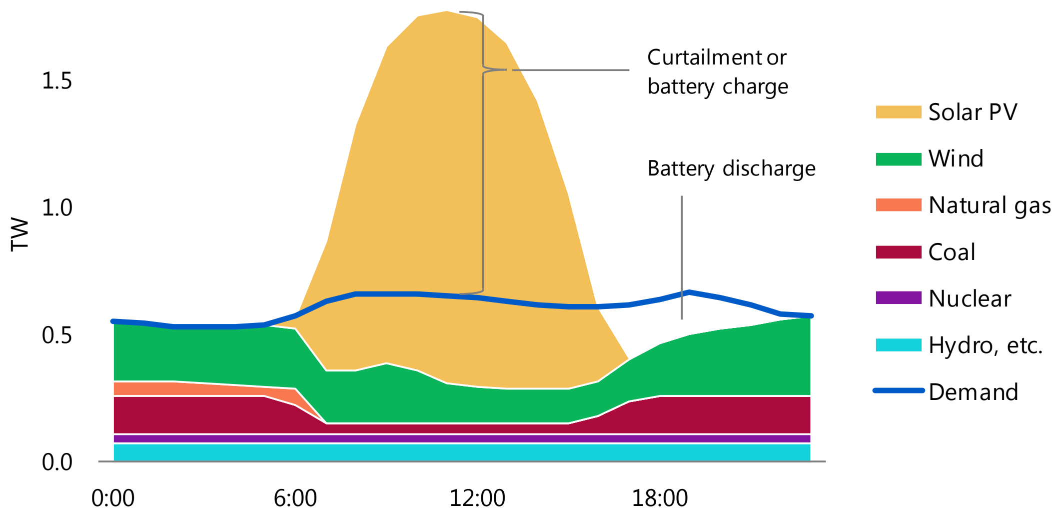


Challenges for stable electricity supply

Electricity supply must constantly be balanced with demand. No supply shortage or excess can be allowed as any supply-demand imbalance could cause a blackout. Solar PV and wind power expansion means not only an increase in power sources that are difficult to control artificially but also a decline in fossil fuel-fired power generation that provided for adjustments to secure high electricity quality and stable supply. The impacts that massive renewable energy power generation required to substitute for all new coal-fired power generation capacity would exert on frequency, voltage and transitional stability have yet to be considered fully and should be addressed urgently.

In India where the ban on new coal-fired power plants will force an increase in solar PV and wind power generation most among countries in the world, daytime power supply will be excessive due to massive solar PV power generation (Figure 7-21). The evening decline in power generation will be rapid, requiring India to substantially expand highly responsive power sources to cover such decline. To avoid any blackout even amid the rapid expansion of renewable energy power generation, India will have to take output curtailment, battery charging / discharging and other measures to secure a supply-demand balance on an order far above the current U.S. peak demand of 0.77 TW.

Figure 7-21 | Indian electricity supply and demand «indicative» [No New Coal-fired Power Plant (Renewables Substitution) Case, 2050]



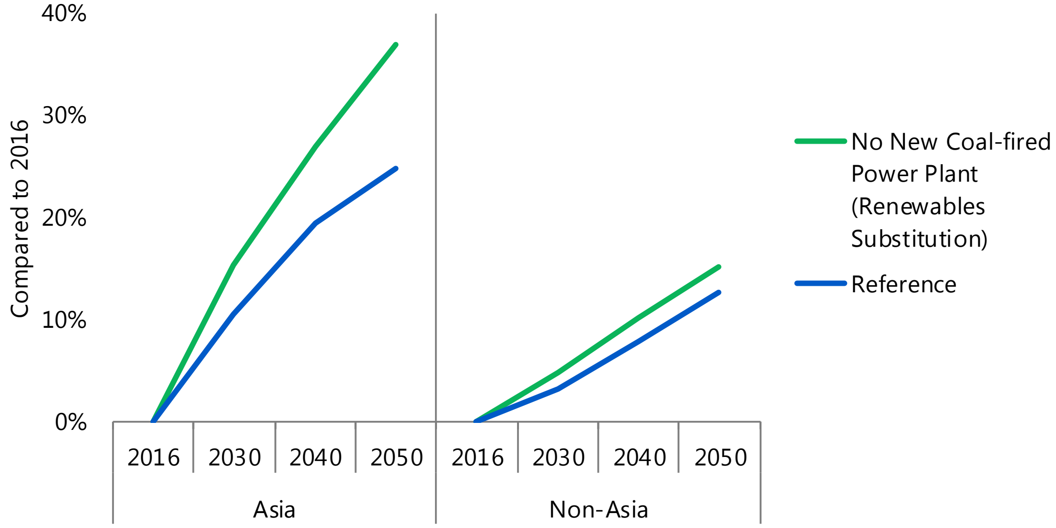
Note: The electricity demand is based on the current demand pattern.

Electricity cost hike

Drastic measures will be required to maintain a stable power supply while substantially expanding intermittent renewable power sources such as solar PV and wind. The expansion will require the introduction of new equipment and a fundamental operating system reform that will drive up electricity costs.

Furthermore, financial resources for economic incentives for the expansion of renewable energy power generation, which have become a problem in many countries, will further the electricity cost hikes. Full attention should be paid to electricity security to avoid problems such as energy poverty and competitive disadvantage.

Figure 7-22 | Electricity costs «indicative»



Notes: Including costs for power generation facilities, fuels and grid-level measures. Based on prices in 2010. Renewable energy power generation equipment costs are assumed to decrease through 2050. The cost decrease (about 30% for solar PV and about 10% for wind by 2050) is based on IEA "World Energy Outlook 2016." Grid-level measure costs are set with reference to OECD/NEA "The Full Costs of Electricity Provision" (2018). Regional characteristics are not considered.

7.4 Multifaceted decisions required

How to face coal-fired power generation

Criticism against coal-fired power generation has grown harsher recently. If a strict policy of banning all new coal-fired power plants is taken, CO_2 emissions in 2050 will be cut by 3 Gt – 7 Gt. In countries or regions where desulfurisation, denitrification and soot / dust removal measures are insufficient, air pollutant emissions will be reduced. However, the subsequent changes we may face will not be limited to only those originally intended. A rapid coal phase-out coincides with explosive consumption growth for substitute energy sources. Although natural gas and renewable energy emit less CO_2 than coal, their massive expansion may bring about new great energy security challenges that should be overcome. It is important to ensure stability of the natural gas supply, stability of the power supply and economic efficiency.

Everyone agrees that the low-carbonisation of the power generation sector is one of the indispensable climate change countermeasures. Countries or regions that can quickly terminate coal-fired power generation should do so steadily. However, Asia faces a high barrier to doing so. Non-Asian developed countries that promote a global coal phase-out must be prepared to support the Asian developing countries' great energy transition.

Realistically, countries or regions that now have difficulties in phasing out coal-fired power generation or have more suitable CO_2 emission reduction measures than the coal phase-out, should consider the priority order of such measures. Even such countries or regions, as a matter of course, should transform inefficient coal-fired power plants into highly efficient ones. They must also pave the way for reducing their dependence on coal-fired power generation.

Take a well-balanced approach

The objective is to address climate change, and the coal phase-out is nothing more than one of the means to achieve the objective. Any means should not be misunderstood as the objective. Coal-fired power generation is not an absolute evil and the hasty dismantlement of coal-fired power generation is not necessarily an essential objective. Comprehensive and multifaceted decisions, widely shared determinations and realistic, foreseeable and careful measures are indispensable for sustainably addressing the super long-term difficult challenge of climate change.

On a larger scale, it should be remembered that climate change is one of the challenges but not the only challenge humankind faces. "For sustainable development to be achieved, it is crucial to harmonise three core elements: economic growth, social inclusion and environmental protection," says the United Nations that has set the Sustainable Development Goals. "These goals are not independent from each other – they need to be implemented in an integrated manner.[41]" A realistic path based on a thorough consideration of the realities of each country or region and a harmonised judgement will lead to a truly faithful approach to the global challenge of sustainable development.

[41] United Nations "Transforming Our World: The 2030 Agenda for Sustainable Development" http://www.unic.or.jp/files/UNDPI_SDG_0707.pptx

Annex

Table A1 | Regional groupings

Asia	People's Republic of China	
	Hong Kong	
	India	
	Japan	
	Korea	
	Chinese Taipei	
	ASEAN	Brunei Darussalam
		Indonesia
		Malaysia
		Myanmar
		Philippines
		Singapore
		Thailand
		Viet Nam
	Others	Bangladesh, D. P. R. Korea, Mongolia, Nepal, Pakistan, Sri Lanka, and Other Asia in IEA statistics
North America	United States	
	Canada	
Latin America	Brazil	
	Chile	
	Mexico	
	Others	Argentina, Bolivia, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela, and Other Non–OECD Americas in IEA statistics
Europe	OECD Europe	France
		Germany
		Italy
		United Kingdom

		Others	Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Iceland, Ireland, Latvia, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, and Turkey
	Non-OECD Europe	Russia	
		Other non-OECD former Soviet Union	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Lithuania, Moldova, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan
		Others	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Gibraltar, Kosovo, Former Yugoslav Republic of Macedonia, Malta, Montenegro, Romania, and Serbia
Africa	Republic of South Africa		
	North Africa	Algeria, Egypt, Libya, Morocco, and Tunisia	
	Others	Angola, Benin, Botswana, Cameroon, Democratic Republic of Congo, Congo, Côte d'Ivoire, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Mozambique, Namibia, Niger, Nigeria, Senegal, South Sudan, Sudan, Togo, United Republic of Tanzania, Zambia, Zimbabwe, and Other Africa in IEA statistics	
Middle East	Iran		
	Iraq		
	Kuwait		
	Oman		
	Qatar		
	Saudi Arabia		
	United Arab Emirates		
	Others	Bahrain, Israel, Jordan, Lebanon, Syrian Arab Republic, and Yemen	
Oceania	Australia		
	New Zealand		
International bunkers			

European Union	Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, the Slovak Republic, Slovenia, Spain, Sweden, and the United Kingdom
OECD	Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States
Organization of the Petroleum Exporting Countries (OPEC)	Algeria, Angola, Republic of the Congo, Ecuador, Equatorial Guinea, Gabon, Iraq, Iran, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela

Notes: (1) Other non-OECD former Soviet Union includes Estonia and Latvia before 1990, and (2) OECD does not include Israel.

Table A2 | Major energy and economic indicators

				Reference		Advanced Technologies		CAGR (%)		
								1990/	2016/2050	
		1990	2016	2030	2050	2030	2050	2016	Reference	Adv. Tech.
Total primary energy	**World**	**8,774**	**13,761**	**16,554**	**19,275**	**15,834**	**16,994**	**1.7**	**1.0**	**0.6**
consumption	OECD	4,522	5,252	5,258	4,918	5,096	4,424	0.6	-0.2	-0.5
(Mtoe)	Non-OECD	4,050	8,111	10,779	13,692	10,259	12,013	2.7	1.6	1.2
	Asia	2,110	5,497	7,327	8,987	6,997	7,917	3.8	1.5	1.1
	Non-Asia	6,461	7,866	8,711	9,622	8,358	8,520	0.8	0.6	0.2
Oil consumption	**World**	**3,234**	**4,390**	**5,052**	**5,628**	**4,681**	**4,543**	**1.2**	**0.7**	**0.1**
(Mtoe)	OECD	1,867	1,887	1,727	1,437	1,602	1,135	0.0	-0.8	-1.5
	Non-OECD	1,165	2,105	2,833	3,600	2,652	3,001	2.3	1.6	1.0
	Asia	618	1,367	1,819	2,207	1,711	1,815	3.1	1.4	0.8
	Non-Asia	2,414	2,625	2,741	2,830	2,544	2,321	0.3	0.2	-0.4
Natural gas	**World**	**1,664**	**3,035**	**3,978**	**5,183**	**3,761**	**4,274**	**2.3**	**1.6**	**1.0**
consumption	OECD	845	1,414	1,578	1,632	1,454	1,204	2.0	0.4	-0.5
(Mtoe)	Non-OECD	818	1,621	2,382	3,497	2,269	2,978	2.7	2.3	1.8
	Asia	116	567	988	1,524	941	1,316	6.3	3.0	2.5
	Non-Asia	1,548	2,468	2,972	3,604	2,782	2,866	1.8	1.1	0.4
Coal consumption	**World**	**2,220**	**3,731**	**4,167**	**4,323**	**3,646**	**2,968**	**2.0**	**0.4**	**-0.7**
(Mtoe)	OECD	1,076	887	747	517	628	304	-0.7	-1.6	-3.1
	Non-OECD	1,144	2,843	3,420	3,806	3,018	2,663	3.6	0.9	-0.2
	Asia	787	2,685	3,238	3,557	2,851	2,502	4.8	0.8	-0.2
	Non-Asia	1,433	1,046	929	766	796	465	-1.2	-0.9	-2.4
Power generation	**World**	**11,852**	**24,973**	**34,470**	**46,915**	**33,592**	**43,245**	**2.9**	**1.9**	**1.6**
(TWh)	OECD	7,640	10,876	12,608	14,006	12,383	13,308	1.4	0.7	0.6
	Non-OECD	4,212	14,097	21,861	32,909	21,209	29,937	4.8	2.5	2.2
	Asia	2,240	10,768	16,728	23,994	16,250	21,851	6.2	2.4	2.1
	Non-Asia	9,611	14,205	17,741	22,922	17,342	21,394	1.5	1.4	1.2
Energy-related	**World**	**20,479**	**32,353**	**37,521**	**41,909**	**33,335**	**28,714**	**1.8**	**0.8**	**-0.4**
carbon dioxide	OECD	10,962	11,549	10,815	9,157	9,560	6,216	0.2	-0.7	-1.8
emissions	Non-OECD	8,888	19,564	25,134	30,788	22,362	21,016	3.1	1.3	0.2
(Mt)	Asia	4,632	14,795	18,891	22,176	16,704	15,090	4.6	1.2	0.1
	Non-Asia	15,218	16,319	17,058	17,769	15,217	12,142	0.3	0.3	-0.9
Primary energy	**World**	**232**	**178**	**142**	**100**	**136**	**89**	**-1.0**	**-1.7**	**-2.0**
consumption	OECD	155	106	82	57	80	51	-1.4	-1.8	-2.1
per GDP	Non-OECD	468	290	205	130	195	114	-1.8	-2.3	-2.7
(toe/$2010 million)	Asia	279	235	171	110	163	97	-0.7	-2.2	-2.6
	Non-Asia	213	146	118	87	114	77	-1.5	-1.5	-1.8
Primary energy	**World**	**1.66**	**1.85**	**1.94**	**1.98**	**1.86**	**1.75**	**0.4**	**0.2**	**-0.2**
consumption	OECD	4.25	4.10	3.87	3.49	3.75	3.14	-0.1	-0.5	-0.8
per capita	Non-OECD	0.96	1.32	1.51	1.64	1.43	1.44	1.2	0.7	0.3
(toe/person)	Asia	0.72	1.36	1.65	1.93	1.58	1.70	2.5	1.0	0.6
	Non-Asia	2.75	2.31	2.14	1.90	2.05	1.68	-0.7	-0.6	-0.9
GDP	**World**	**37,882**	**77,321**	**116,562**	**191,975**	**116,562**	**191,975**	**2.8**	**2.7**	**2.7**
($2010 billion)	OECD	29,234	49,348	63,980	86,697	63,980	86,697	2.0	1.7	1.7
	Non-OECD	8,648	27,973	52,582	105,279	52,582	105,279	4.6	4.0	4.0
	Asia	7,560	23,349	42,947	81,967	42,947	81,967	4.4	3.8	3.8
	Non-Asia	30,322	53,972	73,615	110,008	73,615	110,008	2.2	2.1	2.1
Population	**World**	**5,281**	**7,433**	**8,514**	**9,733**	**8,514**	**9,733**	**1.3**	**0.8**	**0.8**
(Million)	OECD	1,064	1,281	1,358	1,409	1,358	1,409	0.7	0.3	0.3
	Non-OECD	4,216	6,152	7,156	8,324	7,156	8,324	1.5	0.9	0.9
	Asia	2,933	4,035	4,439	4,665	4,439	4,665	1.2	0.4	0.4
	Non-Asia	2,348	3,399	4,075	5,068	4,075	5,068	1.4	1.2	1.2

Table A3 | Population

(Million)

							CAGR (%)				
	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	5,281 (100)	6,113 (100)	7,433 (100)	8,514 (100)	9,172 (100)	9,733 (100)	1.3	1.0	0.7	0.6	0.8
Asia	2,933 (55.5)	3,410 (55.8)	4,035 (54.3)	4,439 (52.1)	4,601 (50.2)	4,665 (47.9)	1.2	0.7	0.4	0.1	0.4
China	1,135 (21.5)	1,263 (20.7)	1,379 (18.5)	1,416 (16.6)	1,393 (15.2)	1,341 (13.8)	0.8	0.2	-0.2	-0.4	-0.1
India	870 (16.5)	1,053 (17.2)	1,324 (17.8)	1,513 (17.8)	1,605 (17.5)	1,659 (17.0)	1.6	1.0	0.6	0.3	0.7
Japan	124 (2.3)	127 (2.1)	127 (1.7)	121 (1.4)	115 (1.2)	108 (1.1)	0.1	-0.4	-0.5	-0.6	-0.5
Korea	43 (0.8)	47 (0.8)	51 (0.7)	53 (0.6)	53 (0.6)	51 (0.5)	0.7	0.3	-0.1	-0.4	0.0
Chinese Taipei	20 (0.4)	22 (0.4)	24 (0.3)	24 (0.3)	24 (0.3)	23 (0.2)	0.6	0.2	-0.1	-0.5	-0.1
ASEAN	430 (8.1)	506 (8.3)	618 (8.3)	700 (8.2)	740 (8.1)	765 (7.9)	1.4	0.9	0.6	0.3	0.6
Indonesia	181 (3.4)	212 (3.5)	261 (3.5)	296 (3.5)	313 (3.4)	322 (3.3)	1.4	0.9	0.6	0.3	0.6
Malaysia	18 (0.3)	23 (0.4)	31 (0.4)	37 (0.4)	40 (0.4)	42 (0.4)	2.1	1.2	0.7	0.5	0.9
Myanmar	41 (0.8)	46 (0.8)	53 (0.7)	59 (0.7)	61 (0.7)	62 (0.6)	1.0	0.8	0.4	0.1	0.5
Philippines	62 (1.2)	78 (1.3)	103 (1.4)	125 (1.5)	139 (1.5)	151 (1.6)	2.0	1.4	1.1	0.8	1.1
Singapore	3 (0.1)	4 (0.1)	6 (0.1)	6 (0.1)	7 (0.1)	7 (0.1)	2.4	0.9	0.3	0.0	0.5
Thailand	57 (1.1)	63 (1.0)	69 (0.9)	70 (0.8)	68 (0.7)	65 (0.7)	0.8	0.1	-0.2	-0.4	-0.2
Viet Nam	68 (1.3)	80 (1.3)	95 (1.3)	106 (1.2)	111 (1.2)	115 (1.2)	1.3	0.8	0.5	0.3	0.6
Non-OECD Asia	2,767 (52.4)	3,236 (52.9)	3,856 (51.9)	4,265 (50.1)	4,434 (48.3)	4,506 (46.3)	1.3	0.7	0.4	0.2	0.5
North America	277 (5.3)	313 (5.1)	359 (4.8)	396 (4.7)	418 (4.6)	436 (4.5)	1.0	0.7	0.5	0.4	0.6
United States	250 (4.7)	282 (4.6)	323 (4.3)	356 (4.2)	375 (4.1)	391 (4.0)	1.0	0.7	0.5	0.4	0.6
Latin America	441 (8.4)	521 (8.5)	634 (8.5)	713 (8.4)	752 (8.2)	775 (8.0)	1.4	0.8	0.5	0.3	0.6
OECD Europe	502 (9.5)	524 (8.6)	569 (7.7)	587 (6.9)	591 (6.4)	590 (6.1)	0.5	0.2	0.1	0.0	0.1
European Union	478 (9.1)	488 (8.0)	511 (6.9)	524 (6.2)	526 (5.7)	523 (5.4)	0.3	0.2	0.0	-0.1	0.1
Non-OECD Europe	341 (6.5)	339 (5.5)	342 (4.6)	345 (4.0)	341 (3.7)	338 (3.5)	0.0	0.1	-0.1	-0.1	0.0
Africa	634 (12.0)	816 (13.4)	1,223 (16.5)	1,701 (20.0)	2,097 (22.9)	2,524 (25.9)	2.6	2.4	2.1	1.9	2.2
Middle East	132 (2.5)	168 (2.8)	242 (3.2)	299 (3.5)	335 (3.6)	367 (3.8)	2.3	1.5	1.1	0.9	1.2
Oceania	20 (0.4)	23 (0.4)	29 (0.4)	34 (0.4)	36 (0.4)	39 (0.4)	1.4	1.1	0.8	0.7	0.9
OECD	1,064 (20.2)	1,150 (18.8)	1,281 (17.2)	1,358 (15.9)	1,391 (15.2)	1,409 (14.5)	0.7	0.4	0.2	0.1	0.3
Non-OECD	4,216 (79.8)	4,963 (81.2)	6,152 (82.8)	7,156 (84.1)	7,781 (84.8)	8,324 (85.5)	1.5	1.1	0.8	0.7	0.9

Source: United Nations "Population Estimates and Projections: The 2017 Revision", World Bank "World Development Indicators"

Note: Figures in parentheses are global shares (%).

Table A4 | GDP

($2010 billion)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/2016	2016/2030	2030/2040	2040/2050	2016/2050
World	37,882 (100)	49,957 (100)	77,321 (100)	116,562 (100)	153,030 (100)	191,975 (100)	2.8	3.0	2.8	2.3	2.7
Asia	7,560 (20.0)	11,025 (22.1)	23,349 (30.2)	42,947 (36.8)	61,820 (40.4)	81,967 (42.7)	4.4	4.4	3.7	2.9	3.8
China	830 (2.2)	2,237 (4.5)	9,504 (12.3)	20,603 (17.7)	31,022 (20.3)	40,505 (21.1)	9.8	5.7	4.2	2.7	4.4
India	465 (1.2)	800 (1.6)	2,456 (3.2)	6,243 (5.4)	10,407 (6.8)	16,104 (8.4)	6.6	6.9	5.2	4.5	5.7
Japan	4,683 (12.4)	5,349 (10.7)	6,053 (7.8)	6,808 (5.8)	7,353 (4.8)	7,885 (4.1)	1.0	0.8	0.8	0.7	0.8
Korea	363 (1.0)	710 (1.4)	1,305 (1.7)	1,873 (1.6)	2,278 (1.5)	2,624 (1.4)	5.0	2.6	2.0	1.4	2.1
Chinese Taipei	155 (0.4)	297 (0.6)	514 (0.7)	684 (0.6)	814 (0.5)	929 (0.5)	4.7	2.1	1.8	1.3	1.8
ASEAN	741 (2.0)	1,180 (2.4)	2,607 (3.4)	5,042 (4.3)	7,503 (4.9)	10,546 (5.5)	5.0	4.8	4.1	3.5	4.2
Indonesia	310 (0.8)	453 (0.9)	1,038 (1.3)	2,138 (1.8)	3,351 (2.2)	4,849 (2.5)	4.8	5.3	4.6	3.8	4.6
Malaysia	82 (0.2)	163 (0.3)	344 (0.4)	646 (0.6)	917 (0.6)	1,236 (0.6)	5.7	4.6	3.6	3.0	3.8
Myanmar	7 (-)	13 (-)	62 (0.1)	150 (0.1)	246 (0.2)	375 (0.2)	9.0	6.5	5.1	4.3	5.4
Philippines	95 (0.2)	125 (0.3)	284 (0.4)	620 (0.5)	915 (0.6)	1,305 (0.7)	4.3	5.7	4.0	3.6	4.6
Singapore	68 (0.2)	134 (0.3)	295 (0.4)	419 (0.4)	501 (0.3)	564 (0.3)	5.8	2.5	1.8	1.2	1.9
Thailand	142 (0.4)	218 (0.4)	406 (0.5)	669 (0.6)	921 (0.6)	1,204 (0.6)	4.1	3.6	3.2	2.7	3.2
Viet Nam	29 (0.1)	61 (0.1)	164 (0.2)	377 (0.3)	622 (0.4)	980 (0.5)	6.8	6.1	5.2	4.6	5.4
Non-OECD Asia	2,515 (6.6)	4,966 (9.9)	15,992 (20.7)	34,266 (29.4)	52,189 (34.1)	71,458 (37.2)	7.4	5.6	4.3	3.2	4.5
North America	10,078 (26.6)	14,056 (28.1)	18,748 (24.2)	25,056 (21.5)	30,555 (20.0)	36,229 (18.9)	2.4	2.1	2.0	1.7	2.0
United States	9,064 (23.9)	12,713 (25.4)	16,920 (21.9)	22,637 (19.4)	27,647 (18.1)	32,825 (17.1)	2.4	2.1	2.0	1.7	2.0
Latin America	2,787 (7.4)	3,778 (7.6)	5,704 (7.4)	8,559 (7.3)	11,723 (7.7)	14,928 (7.8)	2.8	2.9	3.2	2.4	2.9
OECD Europe	12,691 (33.5)	15,934 (31.9)	20,165 (26.1)	25,706 (22.1)	29,301 (19.1)	32,707 (17.0)	1.8	1.7	1.3	1.1	1.4
European Union	11,895 (31.4)	14,789 (29.6)	18,309 (23.7)	23,323 (20.0)	26,643 (17.4)	29,798 (15.5)	1.7	1.7	1.3	1.1	1.4
Non-OECD Europe	2,143 (5.7)	1,497 (3.0)	2,727 (3.5)	3,815 (3.3)	4,817 (3.1)	6,023 (3.1)	0.9	2.4	2.4	2.3	2.4
Africa	876 (2.3)	1,146 (2.3)	2,307 (3.0)	4,168 (3.6)	6,725 (4.4)	9,996 (5.2)	3.8	4.3	4.9	4.0	4.4
Middle East	1,024 (2.7)	1,525 (3.1)	2,749 (3.6)	4,118 (3.5)	5,467 (3.6)	7,075 (3.7)	3.9	2.9	2.9	2.6	2.8
Oceania	721 (1.9)	996 (2.0)	1,570 (2.0)	2,193 (1.9)	2,621 (1.7)	3,050 (1.6)	3.0	2.4	1.8	1.5	2.0
OECD	29,234 (77.2)	38,070 (76.2)	49,348 (63.8)	63,980 (54.9)	75,356 (49.2)	86,697 (45.2)	2.0	1.9	1.6	1.4	1.7
Non-OECD	8,648 (22.8)	11,887 (23.8)	27,973 (36.2)	52,582 (45.1)	77,674 (50.8)	105,279 (54.8)	4.6	4.6	4.0	3.1	4.0

Source: World Bank "World Development Indicators", etc. (historical)

Note: Figures in parentheses are global shares (%).

Table A5 | GDP per capita

($2010 thousand/person)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/2016	2016/2030	2030/2040	2040/2050	2016/2050
World	7.2	8.2	10.4	13.7	16.7	19.7	1.4	2.0	2.0	1.7	1.9
Asia	2.6	3.2	5.8	9.7	13.4	17.6	3.2	3.7	3.3	2.7	3.3
China	0.7	1.8	6.9	14.6	22.3	30.2	9.0	5.5	4.3	3.1	4.4
India	0.5	0.8	1.9	4.1	6.5	9.7	4.9	5.9	4.6	4.1	5.0
Japan	37.9	42.2	47.7	56.3	64.2	72.9	0.9	1.2	1.3	1.3	1.3
Korea	8.5	15.1	25.5	35.2	43.1	51.5	4.3	2.3	2.0	1.8	2.1
Chinese Taipei	7.6	13.3	21.8	28.3	34.2	40.8	4.1	1.9	1.9	1.8	1.9
ASEAN	1.7	2.3	4.2	7.2	10.1	13.8	3.5	3.9	3.5	3.1	3.5
Indonesia	1.7	2.1	4.0	7.2	10.7	15.0	3.3	4.4	4.0	3.4	4.0
Malaysia	4.5	7.0	11.0	17.5	23.1	29.6	3.5	3.4	2.8	2.5	2.9
Myanmar	0.2	0.3	1.2	2.5	4.0	6.0	7.9	5.6	4.6	4.1	4.9
Philippines	1.5	1.6	2.8	4.9	6.6	8.6	2.3	4.3	2.9	2.8	3.4
Singapore	22.2	33.4	52.6	66.2	76.6	86.0	3.4	1.7	1.5	1.2	1.5
Thailand	2.5	3.5	5.9	9.6	13.5	18.4	3.4	3.5	3.4	3.2	3.4
Viet Nam	0.4	0.8	1.7	3.5	5.6	8.5	5.5	5.2	4.7	4.3	4.8
Non-OECD Asia	0.9	1.5	4.1	8.0	11.8	15.9	6.0	4.8	3.9	3.0	4.0
North America	36.3	44.9	52.2	63.2	73.1	83.2	1.4	1.4	1.5	1.3	1.4
United States	36.3	45.1	52.4	63.6	73.7	84.0	1.4	1.4	1.5	1.3	1.4
Latin America	6.3	7.3	9.0	12.0	15.6	19.3	1.4	2.1	2.7	2.1	2.3
OECD Europe	25.3	30.4	35.4	43.8	49.5	55.5	1.3	1.5	1.2	1.1	1.3
European Union	24.9	30.3	35.8	44.5	50.6	56.9	1.4	1.6	1.3	1.2	1.4
Non-OECD Europe	6.3	4.4	8.0	11.1	14.1	17.8	0.9	2.4	2.5	2.4	2.4
Africa	1.4	1.4	1.9	2.5	3.2	4.0	1.2	1.9	2.7	2.1	2.2
Middle East	7.7	9.1	11.4	13.8	16.3	19.3	1.5	1.4	1.7	1.7	1.6
Oceania	35.3	43.3	54.3	65.3	72.0	78.1	1.7	1.3	1.0	0.8	1.1
OECD	27.5	33.1	38.5	47.1	54.2	61.5	1.3	1.5	1.4	1.3	1.4
Non-OECD	2.1	2.4	4.5	7.3	10.0	12.6	3.1	3.5	3.1	2.4	3.1

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)

Table A6 | International energy prices

Real prices			Reference			Advanced Technologies		
		2017	2030	2040	2050	2030	2040	2050
Oil	$2017/bbl	54	95	115	125	80	80	80
Natural gas								
Japan	$2017/MBtu	8.1	10.5	10.7	10.8	9.9	9.9	9.9
Europe (UK)	$2017/MBtu	5.8	8.2	8.8	8.9	7.8	7.8	7.9
United States	$2017/MBtu	3.0	4.2	5.0	5.2	3.8	3.9	4.0
Steam coal	$2017/t	99	96	107	111	85	85	85

Nominal prices			Reference			Advanced Technologies		
		2017	2030	2040	2050	2030	2040	2050
Oil	$/bbl	54	123	181	240	103	126	154
Natural gas								
Japan	$/MBtu	8.1	13.5	16.9	20.8	12.8	15.6	19.0
Europe (UK)	$/MBtu	5.8	10.6	13.9	17.1	10.1	12.3	15.2
United States	$/MBtu	3.0	5.4	7.9	10.0	4.9	6.1	7.7
Steam coal	$/t	99	124	169	213	110	134	163

Note: 2% per annum of inflation rates are assumed.

Table A7 | Primary energy consumption [Reference Scenario]

(Mtoe)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/2016	2016/2030	2030/2040	2040/2050	2016/2050
World	8,774 (100)	10,036 (100)	13,761 (100)	16,554 (100)	18,164 (100)	19,275 (100)	1.7	1.3	0.9	0.6	1.0
Asia	2,110 (24.1)	2,887 (28.8)	5,497 (39.9)	7,327 (44.3)	8,336 (45.9)	8,987 (46.6)	3.8	2.1	1.3	0.8	1.5
China	874 (10.0)	1,130 (11.3)	2,958 (21.5)	3,658 (22.1)	3,915 (21.6)	3,873 (20.1)	4.8	1.5	0.7	-0.1	0.8
India	306 (3.5)	441 (4.4)	862 (6.3)	1,499 (9.1)	1,943 (10.7)	2,357 (12.2)	4.1	4.0	2.6	1.9	3.0
Japan	438 (5.0)	518 (5.2)	426 (3.1)	420 (2.5)	394 (2.2)	367 (1.9)	-0.1	-0.1	-0.6	-0.7	-0.4
Korea	93 (1.1)	188 (1.9)	282 (2.1)	307 (1.9)	304 (1.7)	287 (1.5)	4.4	0.6	-0.1	-0.6	0.0
Chinese Taipei	48 (0.5)	85 (0.8)	110 (0.8)	111 (0.7)	110 (0.6)	105 (0.5)	3.3	0.1	-0.1	-0.5	-0.1
ASEAN	233 (2.7)	379 (3.8)	643 (4.7)	1,011 (6.1)	1,270 (7.0)	1,514 (7.9)	4.0	3.3	2.3	1.8	2.6
Indonesia	99 (1.1)	156 (1.6)	230 (1.7)	390 (2.4)	497 (2.7)	591 (3.1)	3.3	3.8	2.4	1.8	2.8
Malaysia	22 (0.2)	49 (0.5)	89 (0.6)	125 (0.8)	146 (0.8)	161 (0.8)	5.5	2.4	1.6	1.0	1.8
Myanmar	11 (0.1)	13 (0.1)	19 (0.1)	29 (0.2)	38 (0.2)	47 (0.2)	2.3	3.0	2.6	2.1	2.6
Philippines	29 (0.3)	40 (0.4)	55 (0.4)	97 (0.6)	127 (0.7)	161 (0.8)	2.5	4.2	2.7	2.4	3.2
Singapore	12 (0.1)	19 (0.2)	27 (0.2)	34 (0.2)	37 (0.2)	38 (0.2)	3.4	1.5	0.9	0.4	1.0
Thailand	42 (0.5)	72 (0.7)	139 (1.0)	182 (1.1)	215 (1.2)	246 (1.3)	4.7	2.0	1.7	1.4	1.7
Viet Nam	18 (0.2)	29 (0.3)	81 (0.6)	150 (0.9)	207 (1.1)	266 (1.4)	6.0	4.5	3.3	2.5	3.6
Non-OECD Asia	1,579 (18.0)	2,181 (21.7)	4,789 (34.8)	6,600 (39.9)	7,638 (42.0)	8,334 (43.2)	4.4	2.3	1.5	0.9	1.6
North America	2,126 (24.2)	2,527 (25.2)	2,447 (17.8)	2,426 (14.7)	2,357 (13.0)	2,272 (11.8)	0.5	-0.1	-0.3	-0.4	-0.2
United States	1,915 (21.8)	2,274 (22.7)	2,167 (15.7)	2,135 (12.9)	2,074 (11.4)	1,999 (10.4)	0.5	-0.1	-0.3	-0.4	-0.2
Latin America	464 (5.3)	600 (6.0)	840 (6.1)	1,068 (6.5)	1,230 (6.8)	1,325 (6.9)	2.3	1.7	1.4	0.7	1.3
OECD Europe	1,627 (18.5)	1,753 (17.5)	1,723 (12.5)	1,676 (10.1)	1,593 (8.8)	1,519 (7.9)	0.2	-0.2	-0.5	-0.5	-0.4
European Union	1,646 (18.8)	1,695 (16.9)	1,599 (11.6)	1,553 (9.4)	1,475 (8.1)	1,407 (7.3)	-0.1	-0.2	-0.5	-0.5	-0.4
Non-OECD Europe	1,530 (17.4)	1,000 (10.0)	1,130 (8.2)	1,252 (7.6)	1,321 (7.3)	1,403 (7.3)	-1.2	0.7	0.5	0.6	0.6
Africa	392 (4.5)	498 (5.0)	818 (5.9)	1,116 (6.7)	1,390 (7.7)	1,644 (8.5)	2.9	2.2	2.2	1.7	2.1
Middle East	223 (2.5)	372 (3.7)	757 (5.5)	1,019 (6.2)	1,184 (6.5)	1,313 (6.8)	4.8	2.1	1.5	1.0	1.6
Oceania	99 (1.1)	125 (1.2)	151 (1.1)	154 (0.9)	151 (0.8)	145 (0.8)	1.6	0.2	-0.2	-0.4	-0.1
OECD	4,522 (51.5)	5,287 (52.7)	5,252 (38.2)	5,258 (31.8)	5,108 (28.1)	4,918 (25.5)	0.6	0.0	-0.3	-0.4	-0.2
Non-OECD	4,050 (46.2)	4,475 (44.6)	8,111 (58.9)	10,779 (65.1)	12,454 (68.6)	13,692 (71.0)	2.7	2.1	1.5	1.0	1.6

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A8 | Primary energy consumption, coal [Reference Scenario]

(Mtoe)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/2016	2016/2030	2030/2040	2040/2050	2016/2050
World	2,220	2,316	3,731	4,167	4,352	4,323	2.0	0.8	0.4	-0.1	0.4
	(100)	(100)	(100)	(100)	(100)	(100)					
Asia	787	1,036	2,685	3,238	3,505	3,557	4.8	1.3	0.8	0.1	0.8
	(35.5)	(44.7)	(72.0)	(77.7)	(80.5)	(82.3)					
China	531	665	1,916	2,035	2,014	1,817	5.1	0.4	-0.1	-1.0	-0.2
	(23.9)	(28.7)	(51.4)	(48.8)	(46.3)	(42.0)					
India	93	146	380	694	892	1,068	5.6	4.4	2.5	1.8	3.1
	(4.2)	(6.3)	(10.2)	(16.6)	(20.5)	(24.7)					
Japan	76	97	114	103	99	89	1.6	-0.8	-0.4	-1.0	-0.7
	(3.4)	(4.2)	(3.1)	(2.5)	(2.3)	(2.1)					
Korea	25	42	81	89	88	81	4.6	0.6	0.0	-0.8	0.0
	(1.1)	(1.8)	(2.2)	(2.1)	(2.0)	(1.9)					
Chinese Taipei	11	30	41	42	39	33	5.0	0.2	-0.9	-1.5	-0.6
	(0.5)	(1.3)	(1.1)	(1.0)	(0.9)	(0.8)					
ASEAN	13	32	120	233	316	395	9.1	4.8	3.1	2.3	3.6
	(0.6)	(1.4)	(3.2)	(5.6)	(7.3)	(9.1)					
Indonesia	4	12	43	88	124	158	10.1	5.2	3.5	2.5	3.9
	(0.2)	(0.5)	(1.2)	(2.1)	(2.9)	(3.7)					
Malaysia	1	2	19	33	39	43	10.6	4.2	1.7	0.9	2.5
	(0.1)	(0.1)	(0.5)	(0.8)	(0.9)	(1.0)					
Myanmar	-	-	-	4	7	10	6.9	17.5	6.0	4.9	10.2
	(-)	(-)	(-)	(0.1)	(0.1)	(0.2)					
Philippines	2	5	14	25	33	40	9.0	4.1	2.6	2.1	3.1
	(0.1)	(0.2)	(0.4)	(0.6)	(0.7)	(0.9)					
Singapore	-	-	-	-	-	-	12.2	0.2	-0.1	-0.8	-0.2
	(-)	(-)	(-)	(-)	(-)	(-)					
Thailand	4	8	15	20	23	25	5.5	2.0	1.2	0.7	1.4
	(0.2)	(0.3)	(0.4)	(0.5)	(0.5)	(0.6)					
Viet Nam	2	4	28	62	90	118	10.2	5.9	3.8	2.8	4.4
	(0.1)	(0.2)	(0.7)	(1.5)	(2.1)	(2.7)					
Non-OECD Asia	686	898	2,489	3,047	3,318	3,387	5.1	1.5	0.9	0.2	0.9
	(30.9)	(38.8)	(66.7)	(73.1)	(76.2)	(78.4)					
North America	484	566	359	275	207	144	-1.2	-1.9	-2.8	-3.6	-2.6
	(21.8)	(24.4)	(9.6)	(6.6)	(4.8)	(3.3)					
United States	460	534	342	273	205	142	-1.1	-1.6	-2.8	-3.6	-2.5
	(20.7)	(23.1)	(9.2)	(6.5)	(4.7)	(3.3)					
Latin America	21	27	45	55	68	74	2.9	1.5	2.1	0.8	1.5
	(1.0)	(1.2)	(1.2)	(1.3)	(1.6)	(1.7)					
OECD Europe	448	331	269	219	177	146	-1.9	-1.5	-2.1	-1.9	-1.8
	(20.2)	(14.3)	(7.2)	(5.3)	(4.1)	(3.4)					
European Union	454	321	241	196	159	131	-2.4	-1.5	-2.1	-1.9	-1.8
	(20.5)	(13.9)	(6.5)	(4.7)	(3.7)	(3.0)					
Non-OECD Europe	367	209	212	200	198	193	-2.1	-0.4	-0.1	-0.2	-0.3
	(16.5)	(9.0)	(5.7)	(4.8)	(4.5)	(4.5)					
Africa	74	90	108	128	149	166	1.5	1.2	1.5	1.1	1.3
	(3.3)	(3.9)	(2.9)	(3.1)	(3.4)	(3.8)					
Middle East	3	8	9	13	14	14	4.2	2.9	0.8	0.0	1.4
	(0.1)	(0.3)	(0.2)	(0.3)	(0.3)	(0.3)					
Oceania	36	49	45	38	33	28	0.8	-1.2	-1.3	-1.6	-1.3
	(1.6)	(2.1)	(1.2)	(0.9)	(0.8)	(0.7)					
OECD	1,076	1,094	887	747	631	517	-0.7	-1.2	-1.7	-2.0	-1.6
	(48.5)	(47.2)	(23.8)	(17.9)	(14.5)	(12.0)					
Non-OECD	1,144	1,222	2,843	3,420	3,721	3,806	3.6	1.3	0.8	0.2	0.9
	(51.5)	(52.8)	(76.2)	(82.1)	(85.5)	(88.0)					

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A9 | Primary energy consumption, oil [Reference Scenario]

(Mtoe)

							CAGR (%)				
	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	3,234 (100)	3,663 (100)	4,390 (100)	5,052 (100)	5,416 (100)	5,628 (100)	1.2	1.0	0.7	0.4	0.7
Asia	618 (19.1)	916 (25.0)	1,367 (31.1)	1,819 (36.0)	2,052 (37.9)	2,207 (39.2)	3.1	2.1	1.2	0.7	1.4
China	119 (3.7)	221 (6.0)	545 (12.4)	732 (14.5)	774 (14.3)	743 (13.2)	6.0	2.1	0.6	-0.4	0.9
India	61 (1.9)	112 (3.1)	217 (4.9)	390 (7.7)	516 (9.5)	633 (11.3)	5.0	4.3	2.8	2.1	3.2
Japan	250 (7.7)	255 (7.0)	177 (4.0)	144 (2.9)	126 (2.3)	110 (2.0)	-1.3	-1.4	-1.4	-1.3	-1.4
Korea	50 (1.5)	99 (2.7)	110 (2.5)	113 (2.2)	109 (2.0)	100 (1.8)	3.1	0.2	-0.4	-0.8	-0.3
Chinese Taipei	26 (0.8)	38 (1.0)	43 (1.0)	41 (0.8)	39 (0.7)	36 (0.6)	2.0	-0.2	-0.5	-0.8	-0.5
ASEAN	89 (2.7)	153 (4.2)	220 (5.0)	314 (6.2)	386 (7.1)	461 (8.2)	3.6	2.6	2.1	1.8	2.2
Indonesia	33 (1.0)	58 (1.6)	70 (1.6)	104 (2.1)	127 (2.3)	147 (2.6)	2.9	2.8	2.1	1.5	2.2
Malaysia	11 (0.4)	19 (0.5)	31 (0.7)	37 (0.7)	40 (0.7)	42 (0.7)	3.9	1.3	0.8	0.5	0.9
Myanmar	1 (-)	2 (0.1)	4 (0.1)	9 (0.2)	12 (0.2)	15 (0.3)	7.2	4.9	3.2	2.4	3.7
Philippines	11 (0.3)	16 (0.4)	19 (0.4)	36 (0.7)	51 (0.9)	69 (1.2)	2.1	4.9	3.5	3.1	4.0
Singapore	11 (0.4)	17 (0.5)	17 (0.4)	21 (0.4)	24 (0.4)	26 (0.5)	1.6	1.5	1.2	0.7	1.2
Thailand	18 (0.6)	32 (0.9)	55 (1.3)	67 (1.3)	78 (1.4)	88 (1.6)	4.4	1.4	1.5	1.2	1.4
Viet Nam	3 (0.1)	8 (0.2)	22 (0.5)	39 (0.8)	54 (1.0)	73 (1.3)	8.5	4.0	3.3	3.2	3.5
Non-OECD Asia	318 (9.8)	562 (15.3)	1,080 (24.6)	1,561 (30.9)	1,818 (33.6)	1,996 (35.5)	4.8	2.7	1.5	0.9	1.8
North America	833 (25.8)	958 (26.2)	886 (20.2)	806 (15.9)	736 (13.6)	666 (11.8)	0.2	-0.7	-0.9	-1.0	-0.8
United States	757 (23.4)	871 (23.8)	787 (17.9)	712 (14.1)	652 (12.0)	592 (10.5)	0.2	-0.7	-0.9	-1.0	-0.8
Latin America	238 (7.4)	303 (8.3)	361 (8.2)	427 (8.5)	456 (8.4)	452 (8.0)	1.6	1.2	0.7	-0.1	0.7
OECD Europe	611 (18.9)	653 (17.8)	560 (12.8)	499 (9.9)	446 (8.2)	402 (7.1)	-0.3	-0.8	-1.1	-1.0	-1.0
European Union	608 (18.8)	625 (17.1)	522 (11.9)	464 (9.2)	414 (7.6)	371 (6.6)	-0.6	-0.8	-1.1	-1.1	-1.0
Non-OECD Europe	465 (14.4)	202 (5.5)	257 (5.8)	265 (5.2)	272 (5.0)	283 (5.0)	-2.3	0.2	0.3	0.4	0.3
Africa	85 (2.6)	100 (2.7)	184 (4.2)	275 (5.4)	373 (6.9)	459 (8.2)	3.0	2.9	3.1	2.1	2.7
Middle East	146 (4.5)	217 (5.9)	327 (7.5)	421 (8.3)	481 (8.9)	526 (9.4)	3.1	1.8	1.4	0.9	1.4
Oceania	35 (1.1)	40 (1.1)	50 (1.1)	49 (1.0)	46 (0.8)	42 (0.7)	1.4	-0.2	-0.7	-0.8	-0.5
OECD	1,867 (57.7)	2,105 (57.5)	1,887 (43.0)	1,727 (34.2)	1,581 (29.2)	1,437 (25.5)	0.0	-0.6	-0.9	-1.0	-0.8
Non-OECD	1,165 (36.0)	1,284 (35.0)	2,105 (47.9)	2,833 (56.1)	3,281 (60.6)	3,600 (64.0)	2.3	2.1	1.5	0.9	1.6

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A10 | Primary energy consumption, natural gas [Reference Scenario]

(Mtoe)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	1,664 (100)	2,072 (100)	3,035 (100)	3,978 (100)	4,628 (100)	5,183 (100)	2.3	2.0	1.5	1.1	1.6
Asia	116 (7.0)	233 (11.2)	567 (18.7)	988 (24.8)	1,274 (27.5)	1,524 (29.4)	6.3	4.1	2.6	1.8	3.0
China	13 (0.8)	21 (1.0)	171 (5.6)	370 (9.3)	476 (10.3)	554 (10.7)	10.5	5.7	2.6	1.5	3.5
India	11 (0.6)	23 (1.1)	47 (1.5)	127 (3.2)	197 (4.3)	270 (5.2)	5.9	7.4	4.5	3.2	5.3
Japan	44 (2.7)	66 (3.2)	102 (3.4)	96 (2.4)	91 (2.0)	83 (1.6)	3.3	-0.4	-0.5	-0.9	-0.6
Korea	3 (0.2)	17 (0.8)	41 (1.4)	55 (1.4)	63 (1.4)	67 (1.3)	11.0	2.1	1.3	0.6	1.5
Chinese Taipei	1 (0.1)	6 (0.3)	15 (0.5)	22 (0.6)	25 (0.5)	28 (0.5)	9.7	2.6	1.3	0.9	1.7
ASEAN	30 (1.8)	74 (3.6)	139 (4.6)	225 (5.7)	285 (6.2)	339 (6.5)	6.1	3.5	2.4	1.7	2.7
Indonesia	16 (1.0)	27 (1.3)	39 (1.3)	77 (1.9)	108 (2.3)	134 (2.6)	3.5	5.0	3.4	2.1	3.7
Malaysia	7 (0.4)	25 (1.2)	36 (1.2)	49 (1.2)	57 (1.2)	66 (1.3)	6.6	2.3	1.5	1.4	1.8
Myanmar	1 (-)	1 (0.1)	4 (0.1)	5 (0.1)	8 (0.2)	10 (0.2)	6.1	2.7	4.0	3.0	3.2
Philippines	- (-)	- (-)	3 (0.1)	8 (0.2)	12 (0.3)	16 (0.3)	-	6.2	4.3	3.5	4.8
Singapore	- (-)	1 (0.1)	9 (0.3)	10 (0.3)	10 (0.2)	10 (0.2)	-	1.1	0.3	-0.4	0.4
Thailand	5 (0.3)	17 (0.8)	37 (1.2)	49 (1.2)	54 (1.2)	58 (1.1)	8.0	2.0	1.0	0.8	1.4
Viet Nam	- (-)	1 (0.1)	9 (0.3)	24 (0.6)	34 (0.7)	42 (0.8)	36.9	6.9	3.5	2.1	4.5
Non-OECD Asia	69 (4.1)	150 (7.2)	424 (14.0)	837 (21.0)	1,120 (24.2)	1,374 (26.5)	7.2	5.0	3.0	2.1	3.5
North America	493 (29.6)	622 (30.0)	748 (24.6)	842 (21.2)	874 (18.9)	882 (17.0)	1.6	0.9	0.4	0.1	0.5
United States	438 (26.4)	548 (26.4)	653 (21.5)	718 (18.0)	742 (16.0)	747 (14.4)	1.5	0.7	0.3	0.1	0.4
Latin America	72 (4.3)	119 (5.7)	208 (6.9)	278 (7.0)	359 (7.8)	426 (8.2)	4.2	2.1	2.6	1.7	2.1
OECD Europe	262 (15.8)	394 (19.0)	414 (13.6)	452 (11.4)	453 (9.8)	437 (8.4)	1.8	0.6	0.0	-0.3	0.2
European Union	297 (17.9)	396 (19.1)	383 (12.6)	420 (10.6)	422 (9.1)	406 (7.8)	1.0	0.7	0.0	-0.4	0.2
Non-OECD Europe	600 (36.1)	488 (23.5)	529 (17.4)	609 (15.3)	665 (14.4)	713 (13.8)	-0.5	1.0	0.9	0.7	0.9
Africa	30 (1.8)	47 (2.3)	115 (3.8)	194 (4.9)	283 (6.1)	395 (7.6)	5.4	3.8	3.8	3.4	3.7
Middle East	72 (4.3)	145 (7.0)	415 (13.7)	553 (13.9)	640 (13.8)	708 (13.7)	7.0	2.1	1.5	1.0	1.6
Oceania	19 (1.1)	24 (1.2)	39 (1.3)	43 (1.1)	44 (1.0)	43 (0.8)	2.9	0.7	0.3	-0.3	0.3
OECD	845 (50.8)	1,164 (56.2)	1,414 (46.6)	1,578 (39.7)	1,632 (35.3)	1,632 (31.5)	2.0	0.8	0.3	0.0	0.4
Non-OECD	818 (49.2)	908 (43.8)	1,621 (53.4)	2,382 (59.9)	2,960 (64.0)	3,497 (67.5)	2.7	2.8	2.2	1.7	2.3

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A11 | Final energy consumption [Reference Scenario]

(Mtoe)

							CAGR (%)				
	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	6,271	7,035	9,555	11,357	12,446	13,277	1.6	1.2	0.9	0.6	1.0
	(100)	(100)	(100)	(100)	(100)	(100)					
Asia	1,556	1,991	3,709	4,783	5,412	5,887	3.4	1.8	1.2	0.8	1.4
	(24.8)	(28.3)	(38.8)	(42.1)	(43.5)	(44.3)					
China	658	781	1,969	2,365	2,517	2,536	4.3	1.3	0.6	0.1	0.7
	(10.5)	(11.1)	(20.6)	(20.8)	(20.2)	(19.1)					
India	243	314	572	971	1,261	1,538	3.4	3.9	2.6	2.0	2.9
	(3.9)	(4.5)	(6.0)	(8.6)	(10.1)	(11.6)					
Japan	288	331	294	277	261	245	0.1	-0.4	-0.6	-0.6	-0.5
	(4.6)	(4.7)	(3.1)	(2.4)	(2.1)	(1.8)					
Korea	65	127	179	196	197	189	4.0	0.7	0.0	-0.4	0.2
	(1.0)	(1.8)	(1.9)	(1.7)	(1.6)	(1.4)					
Chinese Taipei	29	49	70	72	72	71	3.4	0.2	0.0	-0.2	0.0
	(0.5)	(0.7)	(0.7)	(0.6)	(0.6)	(0.5)					
ASEAN	173	270	451	659	812	960	3.7	2.7	2.1	1.7	2.2
	(2.8)	(3.8)	(4.7)	(5.8)	(6.5)	(7.2)					
Indonesia	80	120	165	241	295	342	2.8	2.8	2.1	1.5	2.2
	(1.3)	(1.7)	(1.7)	(2.1)	(2.4)	(2.6)					
Malaysia	14	30	56	76	87	96	5.5	2.2	1.4	1.0	1.6
	(0.2)	(0.4)	(0.6)	(0.7)	(0.7)	(0.7)					
Myanmar	9	11	16	24	29	35	2.2	2.7	2.1	1.7	2.2
	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)	(0.3)					
Philippines	20	24	32	59	81	108	1.8	4.5	3.2	2.9	3.7
	(0.3)	(0.3)	(0.3)	(0.5)	(0.6)	(0.8)					
Singapore	5	8	18	23	25	26	5.1	1.5	0.9	0.4	1.0
	(0.1)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)					
Thailand	29	51	98	125	147	168	4.8	1.8	1.6	1.4	1.6
	(0.5)	(0.7)	(1.0)	(1.1)	(1.2)	(1.3)					
Viet Nam	16	25	65	110	146	183	5.5	3.9	2.8	2.3	3.1
	(0.3)	(0.4)	(0.7)	(1.0)	(1.2)	(1.4)					
Non-OECD Asia	1,202	1,533	3,236	4,309	4,955	5,453	3.9	2.1	1.4	1.0	1.5
	(19.2)	(21.8)	(33.9)	(37.9)	(39.8)	(41.1)					
North America	1,455	1,738	1,706	1,705	1,669	1,619	0.6	0.0	-0.2	-0.3	-0.2
	(23.2)	(24.7)	(17.9)	(15.0)	(13.4)	(12.2)					
United States	1,294	1,546	1,515	1,508	1,476	1,432	0.6	0.0	-0.2	-0.3	-0.2
	(20.6)	(22.0)	(15.9)	(13.3)	(11.9)	(10.8)					
Latin America	343	447	610	768	876	947	2.2	1.7	1.3	0.8	1.3
	(5.5)	(6.3)	(6.4)	(6.8)	(7.0)	(7.1)					
OECD Europe	1,133	1,231	1,230	1,217	1,166	1,119	0.3	-0.1	-0.4	-0.4	-0.3
	(18.1)	(17.5)	(12.9)	(10.7)	(9.4)	(8.4)					
European Union	1,134	1,179	1,138	1,127	1,078	1,032	0.0	-0.1	-0.4	-0.4	-0.3
	(18.1)	(16.8)	(11.9)	(9.9)	(8.7)	(7.8)					
Non-OECD Europe	1,067	651	713	780	824	876	-1.5	0.6	0.6	0.6	0.6
	(17.0)	(9.3)	(7.5)	(6.9)	(6.6)	(6.6)					
Africa	292	368	594	816	1,012	1,193	2.8	2.3	2.2	1.7	2.1
	(4.7)	(5.2)	(6.2)	(7.2)	(8.1)	(9.0)					
Middle East	157	253	498	672	782	870	4.5	2.2	1.5	1.1	1.7
	(2.5)	(3.6)	(5.2)	(5.9)	(6.3)	(6.6)					
Oceania	66	83	96	101	102	100	1.4	0.4	0.0	-0.1	0.1
	(1.1)	(1.2)	(1.0)	(0.9)	(0.8)	(0.8)					
OECD	3,102	3,625	3,654	3,674	3,589	3,479	0.6	0.0	-0.2	-0.3	-0.1
	(49.5)	(51.5)	(38.2)	(32.3)	(28.8)	(26.2)					
Non-OECD	2,967	3,136	5,503	7,168	8,254	9,133	2.4	1.9	1.4	1.0	1.5
	(47.3)	(44.6)	(57.6)	(63.1)	(66.3)	(68.8)					

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A12 | Final energy consumption, industry [Reference Scenario]

(Mtoe)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/2016	2016/2030	2030/2040	2040/2050	2016/2050
World	1,804	1,868	2,753	3,214	3,535	3,771	1.6	1.1	1.0	0.6	0.9
	(100)	(100)	(100)	(100)	(100)	(100)					
Asia	514	647	1,511	1,789	1,959	2,086	4.2	1.2	0.9	0.6	1.0
	(28.5)	(34.6)	(54.9)	(55.7)	(55.4)	(55.3)					
China	234	302	994	998	986	967	5.7	0.0	-0.1	-0.2	-0.1
	(13.0)	(16.2)	(36.1)	(31.0)	(27.9)	(25.6)					
India	67	83	193	364	473	557	4.2	4.7	2.6	1.7	3.2
	(3.7)	(4.5)	(7.0)	(11.3)	(13.4)	(14.8)					
Japan	106	97	82	79	77	75	-1.0	-0.3	-0.2	-0.3	-0.3
	(5.9)	(5.2)	(3.0)	(2.4)	(2.2)	(2.0)					
Korea	19	38	48	52	52	50	3.6	0.6	0.0	-0.5	0.1
	(1.1)	(2.1)	(1.7)	(1.6)	(1.5)	(1.3)					
Chinese Taipei	12	19	23	24	24	24	2.5	0.2	0.0	-0.3	0.0
	(0.7)	(1.0)	(0.9)	(0.8)	(0.7)	(0.6)					
ASEAN	43	75	129	208	267	317	4.3	3.5	2.5	1.7	2.7
	(2.4)	(4.0)	(4.7)	(6.5)	(7.5)	(8.4)					
Indonesia	18	30	39	65	85	103	3.0	3.7	2.9	1.9	2.9
	(1.0)	(1.6)	(1.4)	(2.0)	(2.4)	(2.7)					
Malaysia	6	12	16	26	32	37	4.2	3.4	2.1	1.3	2.4
	(0.3)	(0.6)	(0.6)	(0.8)	(0.9)	(1.0)					
Myanmar	-	1	2	4	5	7	5.9	5.7	3.7	2.3	4.1
	(-)	(0.1)	(0.1)	(0.1)	(0.2)	(0.2)					
Philippines	5	5	8	14	18	23	1.9	4.2	2.8	2.5	3.3
	(0.3)	(0.3)	(0.3)	(0.4)	(0.5)	(0.6)					
Singapore	1	2	6	7	8	8	9.4	1.3	0.5	-0.2	0.7
	(-)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)					
Thailand	9	17	31	41	50	57	5.1	2.0	1.8	1.4	1.8
	(0.5)	(0.9)	(1.1)	(1.3)	(1.4)	(1.5)					
Viet Nam	5	8	27	51	68	82	7.0	4.7	2.9	2.0	3.4
	(0.3)	(0.4)	(1.0)	(1.6)	(1.9)	(2.2)					
Non-OECD Asia	388	511	1,382	1,658	1,830	1,961	5.0	1.3	1.0	0.7	1.0
	(21.5)	(27.3)	(50.2)	(51.6)	(51.8)	(52.0)					
North America	331	388	306	313	314	304	-0.3	0.2	0.0	-0.3	0.0
	(18.4)	(20.8)	(11.1)	(9.7)	(8.9)	(8.1)					
United States	284	332	264	271	273	265	-0.3	0.2	0.1	-0.3	0.0
	(15.7)	(17.8)	(9.6)	(8.4)	(7.7)	(7.0)					
Latin America	114	148	187	237	283	315	1.9	1.7	1.8	1.1	1.5
	(6.3)	(7.9)	(6.8)	(7.4)	(8.0)	(8.4)					
OECD Europe	327	324	284	287	282	275	-0.5	0.1	-0.2	-0.3	-0.1
	(18.1)	(17.4)	(10.3)	(8.9)	(8.0)	(7.3)					
European Union	345	308	257	262	257	250	-1.1	0.1	-0.2	-0.3	-0.1
	(19.1)	(16.5)	(9.3)	(8.1)	(7.3)	(6.6)					
Non-OECD Europe	394	205	198	223	243	262	-2.6	0.8	0.9	0.8	0.8
	(21.8)	(11.0)	(7.2)	(6.9)	(6.9)	(7.0)					
Africa	55	58	87	132	183	229	1.8	3.0	3.3	2.3	2.9
	(3.1)	(3.1)	(3.2)	(4.1)	(5.2)	(6.1)					
Middle East	47	71	152	204	241	270	4.6	2.1	1.7	1.1	1.7
	(2.6)	(3.8)	(5.5)	(6.3)	(6.8)	(7.2)					
Oceania	23	28	27	30	30	29	0.7	0.6	0.0	-0.4	0.1
	(1.3)	(1.5)	(1.0)	(0.9)	(0.8)	(0.8)					
OECD	835	910	792	818	825	810	-0.2	0.2	0.1	-0.2	0.1
	(46.3)	(48.7)	(28.8)	(25.5)	(23.3)	(21.5)					
Non-OECD	968	957	1,960	2,396	2,710	2,961	2.7	1.4	1.2	0.9	1.2
	(53.7)	(51.3)	(71.2)	(74.5)	(76.7)	(78.5)					

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%).

Table A13 | Final energy consumption, transport [Reference Scenario]

(Mtoe)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	1,570	1,958	2,748	3,238	3,497	3,691	2.2	1.2	0.8	0.5	0.9
	(100)	(100)	(100)	(100)	(100)	(100)					
Asia	184	318	661	969	1,120	1,226	5.1	2.8	1.5	0.9	1.8
	(11.7)	(16.2)	(24.1)	(29.9)	(32.0)	(33.2)					
China	30	84	297	465	501	484	9.2	3.3	0.8	-0.4	1.4
	(1.9)	(4.3)	(10.8)	(14.4)	(14.3)	(13.1)					
India	21	32	90	168	234	299	5.8	4.6	3.4	2.5	3.6
	(1.3)	(1.6)	(3.3)	(5.2)	(6.7)	(8.1)					
Japan	68	86	72	58	51	46	0.2	-1.4	-1.3	-1.2	-1.3
	(4.4)	(4.4)	(2.6)	(1.8)	(1.5)	(1.2)					
Korea	15	26	35	37	35	31	3.4	0.4	-0.7	-1.1	-0.3
	(0.9)	(1.3)	(1.3)	(1.1)	(1.0)	(0.8)					
Chinese Taipei	7	12	13	12	11	9	2.6	-0.5	-1.2	-1.7	-1.1
	(0.4)	(0.6)	(0.5)	(0.4)	(0.3)	(0.2)					
ASEAN	32	61	122	176	220	273	5.2	2.7	2.3	2.2	2.4
	(2.1)	(3.1)	(4.4)	(5.4)	(6.3)	(7.4)					
Indonesia	11	21	47	70	89	109	5.9	2.9	2.4	2.0	2.5
	(0.7)	(1.1)	(1.7)	(2.2)	(2.5)	(2.9)					
Malaysia	5	11	22	24	25	25	5.9	0.8	0.3	0.1	0.4
	(0.3)	(0.6)	(0.8)	(0.7)	(0.7)	(0.7)					
Myanmar	-	1	2	4	5	7	4.9	6.5	3.8	3.4	4.8
	(-)	(0.1)	(0.1)	(0.1)	(0.2)	(0.2)					
Philippines	5	8	11	26	38	53	3.6	5.9	3.9	3.5	4.6
	(0.3)	(0.4)	(0.4)	(0.8)	(1.1)	(1.4)					
Singapore	1	2	2	2	2	2	2.2	-0.1	-0.7	-1.1	-0.6
	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)					
Thailand	9	15	25	29	31	33	4.0	1.0	0.8	0.6	0.8
	(0.6)	(0.7)	(0.9)	(0.9)	(0.9)	(0.9)					
Viet Nam	1	3	12	21	30	43	8.8	3.8	3.6	3.8	3.8
	(0.1)	(0.2)	(0.4)	(0.6)	(0.8)	(1.2)					
Non-OECD Asia	101	206	555	874	1,034	1,149	6.8	3.3	1.7	1.1	2.2
	(6.4)	(10.5)	(20.2)	(27.0)	(29.6)	(31.1)					
North America	531	640	683	637	593	558	1.0	-0.5	-0.7	-0.6	-0.6
	(33.8)	(32.7)	(24.9)	(19.7)	(17.0)	(15.1)					
United States	488	588	622	577	538	507	0.9	-0.5	-0.7	-0.6	-0.6
	(31.0)	(30.0)	(22.6)	(17.8)	(15.4)	(13.7)					
Latin America	103	141	223	284	311	322	3.0	1.7	0.9	0.4	1.1
	(6.6)	(7.2)	(8.1)	(8.8)	(8.9)	(8.7)					
OECD Europe	267	317	343	305	274	250	1.0	-0.8	-1.1	-0.9	-0.9
	(17.0)	(16.2)	(12.5)	(9.4)	(7.8)	(6.8)					
European Union	259	303	319	284	254	231	0.8	-0.8	-1.1	-0.9	-1.0
	(16.5)	(15.5)	(11.6)	(8.8)	(7.3)	(6.3)					
Non-OECD Europe	171	110	145	149	148	148	-0.6	0.2	-0.1	0.0	0.1
	(10.9)	(5.6)	(5.3)	(4.6)	(4.2)	(4.0)					
Africa	38	54	117	165	219	279	4.5	2.5	2.9	2.4	2.6
	(2.4)	(2.8)	(4.3)	(5.1)	(6.3)	(7.5)					
Middle East	51	75	139	174	193	207	3.9	1.6	1.0	0.7	1.2
	(3.2)	(3.8)	(5.1)	(5.4)	(5.5)	(5.6)					
Oceania	24	30	38	38	37	36	1.8	0.0	-0.3	-0.3	-0.2
	(1.5)	(1.5)	(1.4)	(1.2)	(1.0)	(1.0)					
OECD	936	1,140	1,232	1,146	1,063	994	1.1	-0.5	-0.7	-0.7	-0.6
	(59.6)	(58.2)	(44.8)	(35.4)	(30.4)	(26.9)					
Non-OECD	432	544	1,117	1,577	1,832	2,032	3.7	2.5	1.5	1.0	1.8
	(27.5)	(27.8)	(40.7)	(48.7)	(52.4)	(55.0)					

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A14 | Final energy consumption, buildings, etc. [Reference Scenario]

(Mtoe)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	2,417 (100)	2,596 (100)	3,185 (100)	3,807 (100)	4,158 (100)	4,436 (100)	1.1	1.3	0.9	0.7	1.0
Asia	741 (30.7)	842 (32.4)	1,162 (36.5)	1,525 (40.1)	1,750 (42.1)	1,935 (43.6)	1.7	2.0	1.4	1.0	1.5
China	351 (14.5)	338 (13.0)	516 (16.2)	686 (18.0)	778 (18.7)	816 (18.4)	1.5	2.1	1.3	0.5	1.4
India	142 (5.9)	172 (6.6)	243 (7.6)	351 (9.2)	440 (10.6)	545 (12.3)	2.1	2.7	2.3	2.2	2.4
Japan	78 (3.2)	106 (4.1)	104 (3.3)	104 (2.7)	97 (2.3)	91 (2.0)	1.1	0.0	-0.7	-0.7	-0.4
Korea	24 (1.0)	37 (1.4)	46 (1.4)	52 (1.4)	53 (1.3)	53 (1.2)	2.5	0.8	0.3	-0.1	0.4
Chinese Taipei	7 (0.3)	10 (0.4)	12 (0.4)	14 (0.4)	14 (0.3)	15 (0.3)	2.5	0.7	0.6	0.5	0.6
ASEAN	87 (3.6)	113 (4.3)	148 (4.7)	199 (5.2)	230 (5.5)	257 (5.8)	2.1	2.1	1.5	1.1	1.6
Indonesia	44 (1.8)	59 (2.3)	71 (2.2)	95 (2.5)	106 (2.6)	114 (2.6)	1.9	2.1	1.1	0.7	1.4
Malaysia	3 (0.1)	5 (0.2)	9 (0.3)	13 (0.3)	15 (0.4)	17 (0.4)	5.0	2.3	1.7	1.4	1.9
Myanmar	8 (0.4)	9 (0.3)	13 (0.4)	15 (0.4)	17 (0.4)	19 (0.4)	1.6	1.4	1.2	1.0	1.2
Philippines	10 (0.4)	10 (0.4)	11 (0.4)	17 (0.5)	22 (0.5)	26 (0.6)	0.4	3.1	2.1	1.8	2.4
Singapore	1 (-)	2 (0.1)	3 (0.1)	3 (0.1)	3 (0.1)	3 (0.1)	3.2	1.3	0.6	-0.1	0.7
Thailand	11 (0.4)	14 (0.5)	18 (0.6)	22 (0.6)	26 (0.6)	29 (0.6)	2.0	1.5	1.5	1.1	1.4
Viet Nam	10 (0.4)	14 (0.5)	23 (0.7)	33 (0.9)	40 (1.0)	48 (1.1)	3.1	2.7	2.1	1.7	2.2
Non-OECD Asia	639 (26.4)	699 (26.9)	1,012 (31.8)	1,369 (36.0)	1,600 (38.5)	1,792 (40.4)	1.8	2.2	1.6	1.1	1.7
North America	460 (19.0)	537 (20.7)	557 (17.5)	578 (15.2)	577 (13.9)	574 (12.9)	0.7	0.3	0.0	-0.1	0.1
United States	403 (16.7)	473 (18.2)	493 (15.5)	508 (13.3)	509 (12.2)	506 (11.4)	0.8	0.2	0.0	-0.1	0.1
Latin America	100 (4.2)	120 (4.6)	162 (5.1)	201 (5.3)	230 (5.5)	251 (5.7)	1.9	1.6	1.3	0.9	1.3
OECD Europe	438 (18.1)	475 (18.3)	499 (15.7)	515 (13.5)	498 (12.0)	482 (10.9)	0.5	0.2	-0.3	-0.3	-0.1
European Union	430 (17.8)	454 (17.5)	463 (14.5)	480 (12.6)	463 (11.1)	448 (10.1)	0.3	0.2	-0.3	-0.3	-0.1
Non-OECD Europe	436 (18.0)	287 (11.1)	275 (8.6)	292 (7.7)	298 (7.2)	309 (7.0)	-1.8	0.4	0.2	0.4	0.3
Africa	188 (7.8)	241 (9.3)	370 (11.6)	488 (12.8)	569 (13.7)	631 (14.2)	2.6	2.0	1.5	1.0	1.6
Middle East	40 (1.7)	75 (2.9)	136 (4.3)	181 (4.8)	207 (5.0)	226 (5.1)	4.8	2.1	1.3	0.9	1.5
Oceania	15 (0.6)	19 (0.7)	24 (0.8)	27 (0.7)	29 (0.7)	30 (0.7)	1.9	0.8	0.5	0.3	0.6
OECD	1,038 (43.0)	1,205 (46.4)	1,265 (39.7)	1,317 (34.6)	1,300 (31.3)	1,277 (28.8)	0.8	0.3	-0.1	-0.2	0.0
Non-OECD	1,379 (57.0)	1,392 (53.6)	1,920 (60.3)	2,490 (65.4)	2,857 (68.7)	3,160 (71.2)	1.3	1.9	1.4	1.0	1.5

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%).

Table A15 | Final energy consumption, electricity [Reference Scenario]

(TWh)

							CAGR (%)				
	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	9,696 (100)	12,668 (100)	20,860 (100)	28,935 (100)	34,767 (100)	40,477 (100)	3.0	2.4	1.9	1.5	2.0
Asia	1,817 (18.7)	3,228 (25.5)	9,120 (43.7)	14,152 (48.9)	17,581 (50.6)	20,846 (51.5)	6.4	3.2	2.2	1.7	2.5
China	454 (4.7)	1,036 (8.2)	5,176 (24.8)	7,613 (26.3)	8,940 (25.7)	9,863 (24.4)	9.8	2.8	1.6	1.0	1.9
India	215 (2.2)	376 (3.0)	1,110 (5.3)	2,543 (8.8)	3,728 (10.7)	5,102 (12.6)	6.5	6.1	3.9	3.2	4.6
Japan	756 (7.8)	943 (7.4)	967 (4.6)	1,036 (3.6)	1,043 (3.0)	1,029 (2.5)	1.0	0.5	0.1	-0.1	0.2
Korea	94 (1.0)	263 (2.1)	517 (2.5)	625 (2.2)	678 (2.0)	702 (1.7)	6.8	1.4	0.8	0.3	0.9
Chinese Taipei	77 (0.8)	160 (1.3)	236 (1.1)	268 (0.9)	290 (0.8)	307 (0.8)	4.4	0.9	0.8	0.6	0.8
ASEAN	130 (1.3)	320 (2.5)	854 (4.1)	1,616 (5.6)	2,257 (6.5)	2,947 (7.3)	7.5	4.7	3.4	2.7	3.7
Indonesia	28 (0.3)	79 (0.6)	216 (1.0)	458 (1.6)	678 (1.9)	906 (2.2)	8.1	5.5	4.0	3.0	4.3
Malaysia	20 (0.2)	61 (0.5)	144 (0.7)	234 (0.8)	300 (0.9)	361 (0.9)	7.9	3.5	2.5	1.9	2.7
Myanmar	2 (-)	3 (-)	15 (0.1)	45 (0.2)	72 (0.2)	106 (0.3)	8.7	8.0	4.8	4.0	5.8
Philippines	21 (0.2)	37 (0.3)	74 (0.4)	152 (0.5)	218 (0.6)	300 (0.7)	4.9	5.3	3.7	3.2	4.2
Singapore	13 (0.1)	27 (0.2)	49 (0.2)	60 (0.2)	66 (0.2)	67 (0.2)	5.2	1.6	0.8	0.3	1.0
Thailand	38 (0.4)	88 (0.7)	194 (0.9)	292 (1.0)	368 (1.1)	445 (1.1)	6.4	3.0	2.3	1.9	2.5
Viet Nam	6 (0.1)	22 (0.2)	159 (0.8)	369 (1.3)	552 (1.6)	756 (1.9)	13.3	6.2	4.1	3.2	4.7
Non-OECD Asia	967 (10.0)	2,021 (16.0)	7,635 (36.6)	12,492 (43.2)	15,860 (45.6)	19,114 (47.2)	8.3	3.6	2.4	1.9	2.7
North America	3,051 (31.5)	3,980 (31.4)	4,282 (20.5)	5,055 (17.5)	5,461 (15.7)	5,765 (14.2)	1.3	1.2	0.8	0.5	0.9
United States	2,633 (27.2)	3,499 (27.6)	3,807 (18.3)	4,488 (15.5)	4,845 (13.9)	5,109 (12.6)	1.4	1.2	0.8	0.5	0.9
Latin America	517 (5.3)	798 (6.3)	1,313 (6.3)	1,880 (6.5)	2,410 (6.9)	2,882 (7.1)	3.6	2.6	2.5	1.8	2.3
OECD Europe	2,235 (23.1)	2,710 (21.4)	3,097 (14.8)	3,494 (12.1)	3,664 (10.5)	3,772 (9.3)	1.3	0.9	0.5	0.3	0.6
European Union	2,160 (22.3)	2,526 (19.9)	2,784 (13.3)	3,150 (10.9)	3,315 (9.5)	3,421 (8.5)	1.0	0.9	0.5	0.3	0.6
Non-OECD Europe	1,462 (15.1)	1,006 (7.9)	1,238 (5.9)	1,565 (5.4)	1,819 (5.2)	2,091 (5.2)	-0.6	1.7	1.5	1.4	1.6
Africa	257 (2.6)	361 (2.8)	635 (3.0)	1,113 (3.8)	1,774 (5.1)	2,666 (6.6)	3.5	4.1	4.8	4.2	4.3
Middle East	199 (2.0)	379 (3.0)	925 (4.4)	1,372 (4.7)	1,721 (4.9)	2,093 (5.2)	6.1	2.9	2.3	2.0	2.4
Oceania	157 (1.6)	207 (1.6)	250 (1.2)	305 (1.1)	337 (1.0)	363 (0.9)	1.8	1.4	1.0	0.8	1.1
OECD	6,410 (66.1)	8,285 (65.4)	9,454 (45.3)	11,006 (38.0)	11,817 (34.0)	12,394 (30.6)	1.5	1.1	0.7	0.5	0.8
Non-OECD	3,286 (33.9)	4,383 (34.6)	11,406 (54.7)	17,929 (62.0)	22,950 (66.0)	28,083 (69.4)	4.9	3.3	2.5	2.0	2.7

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%).

Table A16 | Electricity generated [Reference Scenario]

(TWh)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	11,852	15,441	24,973	34,470	40,912	46,915	2.9	2.3	1.7	1.4	1.9
	(100)	(100)	(100)	(100)	(100)	(100)					
Asia	2,240	3,983	10,768	16,728	20,542	23,994	6.2	3.2	2.1	1.6	2.4
	(18.9)	(25.8)	(43.1)	(48.5)	(50.2)	(51.1)					
China	621	1,356	6,187	9,019	10,463	11,388	9.2	2.7	1.5	0.9	1.8
	(5.2)	(8.8)	(24.8)	(26.2)	(25.6)	(24.3)					
India	293	570	1,478	3,285	4,628	6,086	6.4	5.9	3.5	2.8	4.3
	(2.5)	(3.7)	(5.9)	(9.5)	(11.3)	(13.0)					
Japan	861	1,058	1,052	1,125	1,130	1,112	0.8	0.5	0.0	-0.2	0.2
	(7.3)	(6.9)	(4.2)	(3.3)	(2.8)	(2.4)					
Korea	105	289	559	677	736	761	6.6	1.4	0.8	0.3	0.9
	(0.9)	(1.9)	(2.2)	(2.0)	(1.8)	(1.6)					
Chinese Taipei	88	181	261	295	319	338	4.2	0.9	0.8	0.6	0.8
	(0.7)	(1.2)	(1.0)	(0.9)	(0.8)	(0.7)					
ASEAN	154	370	926	1,780	2,493	3,251	7.1	4.8	3.4	2.7	3.8
	(1.3)	(2.4)	(3.7)	(5.2)	(6.1)	(6.9)					
Indonesia	33	93	249	525	773	1,026	8.1	5.5	3.9	2.9	4.3
	(0.3)	(0.6)	(1.0)	(1.5)	(1.9)	(2.2)					
Malaysia	23	69	157	257	330	398	7.7	3.6	2.5	1.9	2.8
	(0.2)	(0.4)	(0.6)	(0.7)	(0.8)	(0.8)					
Myanmar	2	5	18	72	112	160	7.9	10.5	4.5	3.6	6.7
	(-)	(-)	(0.1)	(0.2)	(0.3)	(0.3)					
Philippines	26	45	91	184	260	351	4.9	5.2	3.5	3.1	4.1
	(0.2)	(0.3)	(0.4)	(0.5)	(0.6)	(0.7)					
Singapore	16	32	52	64	70	71	4.7	1.6	0.8	0.2	1.0
	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)					
Thailand	44	96	191	273	342	413	5.8	2.6	2.3	1.9	2.3
	(0.4)	(0.6)	(0.8)	(0.8)	(0.8)	(0.9)					
Viet Nam	9	27	165	398	601	825	12.0	6.5	4.2	3.2	4.9
	(0.1)	(0.2)	(0.7)	(1.2)	(1.5)	(1.8)					
Non-OECD Asia	1,274	2,636	9,157	14,926	18,677	22,120	7.9	3.6	2.3	1.7	2.6
	(10.8)	(17.1)	(36.7)	(43.3)	(45.7)	(47.1)					
North America	3,685	4,631	4,967	5,831	6,256	6,554	1.2	1.2	0.7	0.5	0.8
	(31.1)	(30.0)	(19.9)	(16.9)	(15.3)	(14.0)					
United States	3,203	4,026	4,300	5,060	5,439	5,703	1.1	1.2	0.7	0.5	0.8
	(27.0)	(26.1)	(17.2)	(14.7)	(13.3)	(12.2)					
Latin America	623	1,009	1,628	2,299	2,893	3,386	3.8	2.5	2.3	1.6	2.2
	(5.3)	(6.5)	(6.5)	(6.7)	(7.1)	(7.2)					
OECD Europe	2,668	3,227	3,599	4,037	4,201	4,287	1.2	0.8	0.4	0.2	0.5
	(22.5)	(20.9)	(14.4)	(11.7)	(10.3)	(9.1)					
European Union	2,577	3,006	3,228	3,654	3,839	3,950	0.9	0.9	0.5	0.3	0.6
	(21.7)	(19.5)	(12.9)	(10.6)	(9.4)	(8.4)					
Non-OECD Europe	1,888	1,428	1,764	2,147	2,390	2,625	-0.3	1.4	1.1	0.9	1.2
	(15.9)	(9.2)	(7.1)	(6.2)	(5.8)	(5.6)					
Africa	316	442	801	1,372	2,139	3,141	3.6	3.9	4.5	3.9	4.1
	(2.7)	(2.9)	(3.2)	(4.0)	(5.2)	(6.7)					
Middle East	244	472	1,147	1,694	2,096	2,510	6.1	2.8	2.2	1.8	2.3
	(2.1)	(3.1)	(4.6)	(4.9)	(5.1)	(5.3)					
Oceania	187	249	299	361	395	420	1.8	1.4	0.9	0.6	1.0
	(1.6)	(1.6)	(1.2)	(1.0)	(1.0)	(0.9)					
OECD	7,640	9,700	10,876	12,608	13,453	14,006	1.4	1.1	0.7	0.4	0.7
	(64.5)	(62.8)	(43.6)	(36.6)	(32.9)	(29.9)					
Non-OECD	4,212	5,741	14,097	21,861	27,459	32,909	4.8	3.2	2.3	1.8	2.5
	(35.5)	(37.2)	(56.4)	(63.4)	(67.1)	(70.1)					

Source: International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%).

Table A17 | Primary energy consumption per capita [Reference Scenario]

(toe/person)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	1.66	1.64	1.85	1.94	1.98	1.98	0.4	0.4	0.2	0.0	0.2
Asia	0.72	0.85	1.36	1.65	1.81	1.93	2.5	1.4	0.9	0.6	1.0
China	0.77	0.89	2.15	2.58	2.81	2.89	4.0	1.3	0.8	0.3	0.9
India	0.35	0.42	0.65	0.99	1.21	1.42	2.4	3.0	2.0	1.6	2.3
Japan	3.55	4.08	3.35	3.47	3.44	3.39	-0.2	0.3	-0.1	-0.1	0.0
Korea	2.17	4.00	5.51	5.78	5.75	5.63	3.7	0.3	0.0	-0.2	0.1
Chinese Taipei	2.34	3.81	4.66	4.59	4.60	4.59	2.7	-0.1	0.0	0.0	0.0
ASEAN	0.54	0.75	1.04	1.44	1.72	1.98	2.5	2.4	1.7	1.4	1.9
Indonesia	0.54	0.74	0.88	1.32	1.59	1.83	1.9	2.9	1.9	1.4	2.2
Malaysia	1.21	2.11	2.85	3.38	3.68	3.86	3.3	1.2	0.8	0.5	0.9
Myanmar	0.26	0.28	0.37	0.50	0.61	0.75	1.3	2.2	2.1	2.0	2.1
Philippines	0.46	0.51	0.53	0.78	0.91	1.06	0.5	2.8	1.6	1.6	2.1
Singapore	3.78	4.63	4.88	5.31	5.62	5.83	1.0	0.6	0.6	0.4	0.5
Thailand	0.74	1.15	2.01	2.62	3.14	3.77	3.9	1.9	1.9	1.8	1.9
Viet Nam	0.26	0.36	0.86	1.42	1.86	2.32	4.7	3.7	2.8	2.2	3.0
Non-OECD Asia	0.57	0.67	1.24	1.55	1.72	1.85	3.0	1.6	1.1	0.7	1.2
North America	7.66	8.08	6.81	6.12	5.64	5.22	-0.5	-0.8	-0.8	-0.8	-0.8
United States	7.67	8.06	6.71	6.00	5.53	5.12	-0.5	-0.8	-0.8	-0.8	-0.8
Latin America	1.05	1.15	1.33	1.50	1.64	1.71	0.9	0.9	0.9	0.4	0.8
OECD Europe	3.24	3.35	3.03	2.86	2.69	2.58	-0.3	-0.4	-0.6	-0.4	-0.5
European Union	3.44	3.47	3.13	2.96	2.80	2.69	-0.4	-0.4	-0.6	-0.4	-0.4
Non-OECD Europe	4.48	2.95	3.30	3.63	3.87	4.16	-1.2	0.7	0.7	0.7	0.7
Africa	0.62	0.61	0.67	0.66	0.66	0.65	0.3	-0.1	0.1	-0.2	-0.1
Middle East	1.68	2.21	3.13	3.41	3.54	3.58	2.4	0.6	0.4	0.1	0.4
Oceania	4.85	5.44	5.22	4.60	4.15	3.71	0.3	-0.9	-1.0	-1.1	-1.0
OECD	4.25	4.60	4.10	3.87	3.67	3.49	-0.1	-0.4	-0.5	-0.5	-0.5
Non-OECD	0.96	0.90	1.32	1.51	1.60	1.64	1.2	1.0	0.6	0.3	0.7

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)

Note: World includes international bunkers.

Table A18 | Primary energy consumption per GDP [Reference Scenario]

(toe/$2010 million)

	1990	2000	2016	2030	2040	2050	CAGR (%) 1990/2016	2016/2030	2030/2040	2040/2050	2016/2050
World	232	201	178	142	119	100	-1.0	-1.6	-1.8	-1.7	-1.7
Asia	279	262	235	171	135	110	-0.7	-2.3	-2.3	-2.0	-2.2
China	1,053	505	311	178	126	96	-4.6	-3.9	-3.4	-2.7	-3.4
India	658	551	351	240	187	146	-2.4	-2.7	-2.5	-2.4	-2.5
Japan	94	97	70	62	54	46	-1.1	-0.9	-1.4	-1.4	-1.2
Korea	256	265	216	164	134	109	-0.6	-2.0	-2.0	-2.0	-2.0
Chinese Taipei	308	286	213	162	135	112	-1.4	-1.9	-1.8	-1.8	-1.9
ASEAN	314	322	247	201	169	144	-0.9	-1.5	-1.7	-1.6	-1.6
Indonesia	318	343	222	182	148	122	-1.4	-1.4	-2.1	-1.9	-1.7
Malaysia	267	301	258	193	159	130	-0.1	-2.1	-1.9	-2.0	-2.0
Myanmar	1,594	960	310	196	153	124	-6.1	-3.2	-2.4	-2.1	-2.7
Philippines	304	319	193	157	139	123	-1.7	-1.4	-1.3	-1.2	-1.3
Singapore	171	139	93	80	73	68	-2.3	-1.0	-0.9	-0.8	-0.9
Thailand	296	332	341	272	233	204	0.5	-1.6	-1.5	-1.3	-1.5
Viet Nam	607	470	494	399	333	272	-0.8	-1.5	-1.8	-2.0	-1.7
Non-OECD Asia	628	439	299	193	146	117	-2.8	-3.1	-2.7	-2.2	-2.7
North America	211	180	131	97	77	63	-1.8	-2.1	-2.2	-2.0	-2.1
United States	211	179	128	94	75	61	-1.9	-2.2	-2.3	-2.1	-2.2
Latin America	167	159	147	125	105	89	-0.5	-1.2	-1.7	-1.7	-1.5
OECD Europe	128	110	85	65	54	46	-1.5	-1.9	-1.8	-1.6	-1.8
European Union	138	115	87	67	55	47	-1.8	-1.9	-1.8	-1.6	-1.8
Non-OECD Europe	714	668	414	328	274	233	-2.1	-1.7	-1.8	-1.6	-1.7
Africa	447	434	354	268	207	164	-0.9	-2.0	-2.5	-2.3	-2.2
Middle East	217	244	275	247	217	186	0.9	-0.8	-1.3	-1.5	-1.2
Oceania	137	126	96	70	58	48	-1.4	-2.2	-2.0	-1.9	-2.0
OECD	155	139	106	82	68	57	-1.4	-1.8	-1.9	-1.8	-1.8
Non-OECD	468	376	290	205	160	130	-1.8	-2.4	-2.4	-2.1	-2.3

Source: World Bank "World Development Indicators", International Energy Agency "World Energy Balances", etc. (historical)

Note: World includes international bunkers.

Table A19 | Energy-related carbon dioxide emissions [Reference Scenario]

(Mt)

							CAGR (%)				
	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2040	2040/ 2050	2016/ 2050
World	20,479	23,113	32,353	37,521	40,407	41,909	1.8	1.1	0.7	0.4	0.8
	(100)	(100)	(100)	(100)	(100)	(100)					
Asia	4,632	6,720	14,795	18,891	21,064	22,176	4.6	1.8	1.1	0.5	1.2
	(22.6)	(29.1)	(45.7)	(50.3)	(52.1)	(52.9)					
China	2,136	3,126	9,015	10,267	10,433	9,706	5.7	0.9	0.2	-0.7	0.2
	(10.4)	(13.5)	(27.9)	(27.4)	(25.8)	(23.2)					
India	529	885	2,078	3,921	5,180	6,343	5.4	4.6	2.8	2.0	3.3
	(2.6)	(3.8)	(6.4)	(10.5)	(12.8)	(15.1)					
Japan	1,046	1,145	1,138	984	902	802	0.3	-1.0	-0.9	-1.2	-1.0
	(5.1)	(5.0)	(3.5)	(2.6)	(2.2)	(1.9)					
Korea	215	414	601	659	660	621	4.0	0.7	0.0	-0.6	0.1
	(1.1)	(1.8)	(1.9)	(1.8)	(1.6)	(1.5)					
Chinese Taipei	110	214	261	276	263	239	3.4	0.4	-0.5	-1.0	-0.3
	(0.5)	(0.9)	(0.8)	(0.7)	(0.7)	(0.6)					
ASEAN	348	676	1,298	2,158	2,793	3,403	5.2	3.7	2.6	2.0	2.9
	(1.7)	(2.9)	(4.0)	(5.8)	(6.9)	(8.1)					
Indonesia	133	255	455	811	1,089	1,339	4.8	4.2	3.0	2.1	3.2
	(0.7)	(1.1)	(1.4)	(2.2)	(2.7)	(3.2)					
Malaysia	54	115	223	318	362	394	5.6	2.6	1.3	0.9	1.7
	(0.3)	(0.5)	(0.7)	(0.8)	(0.9)	(0.9)					
Myanmar	4	9	21	49	75	106	6.6	6.3	4.3	3.5	4.9
	(-)	(-)	(0.1)	(0.1)	(0.2)	(0.3)					
Philippines	36	67	115	218	297	386	4.5	4.7	3.1	2.7	3.6
	(0.2)	(0.3)	(0.4)	(0.6)	(0.7)	(0.9)					
Singapore	22	34	47	53	56	56	2.9	1.0	0.5	-0.1	0.5
	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)					
Thailand	78	147	245	300	332	355	4.5	1.5	1.0	0.7	1.1
	(0.4)	(0.6)	(0.8)	(0.8)	(0.8)	(0.8)					
Viet Nam	17	43	187	402	576	760	9.7	5.6	3.7	2.8	4.2
	(0.1)	(0.2)	(0.6)	(1.1)	(1.4)	(1.8)					
Non-OECD Asia	3,371	5,162	13,057	17,249	19,501	20,753	5.3	2.0	1.2	0.6	1.4
	(16.5)	(22.3)	(40.4)	(46.0)	(48.3)	(49.5)					
North America	5,226	6,203	5,409	5,008	4,585	4,153	0.1	-0.5	-0.9	-1.0	-0.8
	(25.5)	(26.8)	(16.7)	(13.3)	(11.3)	(9.9)					
United States	4,817	5,700	4,870	4,482	4,075	3,668	0.0	-0.6	-0.9	-1.0	-0.8
	(23.5)	(24.7)	(15.1)	(11.9)	(10.1)	(8.8)					
Latin America	853	1,169	1,603	1,977	2,280	2,433	2.5	1.5	1.4	0.7	1.2
	(4.2)	(5.1)	(5.0)	(5.3)	(5.6)	(5.8)					
OECD Europe	3,908	3,902	3,466	3,162	2,837	2,544	-0.5	-0.7	-1.1	-1.1	-0.9
	(19.1)	(16.9)	(10.7)	(8.4)	(7.0)	(6.1)					
European Union	4,018	3,798	3,195	2,859	2,560	2,286	-0.9	-0.8	-1.1	-1.1	-1.0
	(19.6)	(16.4)	(9.9)	(7.6)	(6.3)	(5.5)					
Non-OECD Europe	3,840	2,296	2,425	2,525	2,618	2,683	-1.8	0.3	0.4	0.2	0.3
	(18.8)	(9.9)	(7.5)	(6.7)	(6.5)	(6.4)					
Africa	538	661	1,155	1,644	2,191	2,743	3.0	2.6	2.9	2.3	2.6
	(2.6)	(2.9)	(3.6)	(4.4)	(5.4)	(6.5)					
Middle East	571	948	1,837	2,341	2,649	2,870	4.6	1.7	1.2	0.8	1.3
	(2.8)	(4.1)	(5.7)	(6.2)	(6.6)	(6.8)					
Oceania	282	363	423	402	376	343	1.6	-0.4	-0.7	-0.9	-0.6
	(1.4)	(1.6)	(1.3)	(1.1)	(0.9)	(0.8)					
OECD	10,962	12,421	11,549	10,815	10,023	9,157	0.2	-0.5	-0.8	-0.9	-0.7
	(53.5)	(53.7)	(35.7)	(28.8)	(24.8)	(21.8)					
Non-OECD	8,888	9,841	19,564	25,134	28,577	30,788	3.1	1.8	1.3	0.7	1.3
	(43.4)	(42.6)	(60.5)	(67.0)	(70.7)	(73.5)					

Source: Compiled from International Energy Agency "World Energy Balances" (historical)

Note: Figures in parentheses are global shares (%). World includes international bunkers.

Table A20 | World [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	7,208	8,774	10,036	13,761	16,554	18,164	19,275	100	100	100	1.7	1.3	0.8	1.0
Coal	1,783	2,220	2,316	3,731	4,167	4,352	4,323	25	27	22	2.0	0.8	0.2	0.4
Oil	3,105	3,234	3,663	4,390	5,052	5,416	5,628	37	32	29	1.2	1.0	0.5	0.7
Natural gas	1,232	1,664	2,072	3,035	3,978	4,628	5,183	19	22	27	2.3	2.0	1.3	1.6
Nuclear	186	526	675	680	814	856	911	6.0	4.9	4.7	1.0	1.3	0.6	0.9
Hydro	148	184	225	349	425	466	501	2.1	2.5	2.6	2.5	1.4	0.8	1.1
Geothermal	12	34	52	81	183	234	283	0.4	0.6	1.5	3.4	6.0	2.2	3.8
Solar, wind, etc.	0.1	2.5	8.0	145	389	572	762	-	1.1	4.0	17.0	7.3	3.4	5.0
Biomass and waste	742	909	1,022	1,349	1,545	1,640	1,683	10	9.8	8.7	1.5	1.0	0.4	0.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	5,368	6,271	7,035	9,555	11,357	12,446	13,277	100	100	100	1.6	1.2	0.8	1.0
Industry	1,766	1,804	1,868	2,753	3,214	3,535	3,771	29	29	28	1.6	1.1	0.8	0.9
Transport	1,246	1,570	1,958	2,748	3,238	3,497	3,691	25	29	28	2.2	1.2	0.7	0.9
Buildings, etc.	2,002	2,417	2,596	3,185	3,807	4,158	4,436	39	33	33	1.1	1.3	0.8	1.0
Non-energy use	354	480	614	870	1,098	1,256	1,379	7.6	9.1	10	2.3	1.7	1.1	1.4
Coal	703	752	542	1,036	1,050	1,050	1,020	12	11	7.7	1.2	0.1	-0.1	0.0
Oil	2,446	2,605	3,122	3,908	4,536	4,874	5,094	42	41	38	1.6	1.1	0.6	0.8
Natural gas	815	945	1,118	1,440	1,798	2,007	2,163	15	15	16	1.6	1.6	0.9	1.2
Electricity	586	834	1,089	1,794	2,488	2,990	3,481	13	19	26	3.0	2.4	1.7	2.0
Heat	121	336	248	283	293	297	298	5.4	3.0	2.2	-0.7	0.2	0.1	0.2
Hydrogen	-	-	-	-	0.7	1.2	1.3	-	-	-	n.a.	n.a.	3.1	n.a.
Renewables	698	799	916	1,095	1,191	1,228	1,220	13	11	9.2	1.2	0.6	0.1	0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	8,283	11,852	15,441	24,973	34,470	40,912	46,915	100	100	100	2.9	2.3	1.6	1.9
Coal	3,137	4,430	6,001	9,594	11,873	13,096	13,912	37	38	30	3.0	1.5	0.8	1.1
Oil	1,659	1,323	1,212	931	981	992	893	11	3.7	1.9	-1.3	0.4	-0.5	-0.1
Natural gas	999	1,750	2,747	5,794	8,587	11,012	13,538	15	23	29	4.7	2.9	2.3	2.5
Nuclear	713	2,013	2,591	2,606	3,122	3,287	3,496	17	10	7.5	1.0	1.3	0.6	0.9
Hydro	1,717	2,144	2,618	4,061	4,940	5,415	5,824	18	16	12	2.5	1.4	0.8	1.1
Geothermal	14	36	52	82	195	254	307	0.3	0.3	0.7	3.2	6.4	2.3	4.0
Solar PV	-	0.1	1.0	328	1,229	1,923	2,653	-	1.3	5.7	37.3	9.9	3.9	6.3
Wind	-	3.9	31	958	2,446	3,501	4,506	-	3.8	9.6	23.6	6.9	3.1	4.7
CSP and marine	0.5	1.2	1.1	12	119	214	351	-	-	0.7	9.1	18.1	5.6	10.6
Biomass and waste	44	130	164	571	942	1,182	1,399	1.1	2.3	3.0	5.9	3.6	2.0	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	37	37	37	37	0.2	0.1	0.1	2.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	28,090	37,882	49,957	77,321	116,562	153,030	191,975	2.8	3.0	2.5	2.7
Population (million)	4,437	5,281	6,113	7,433	8,514	9,172	9,733	1.3	1.0	0.7	0.8
CO_2 emissions (Mt)	17,808	20,479	23,113	32,353	37,521	40,407	41,909	1.8	1.1	0.6	0.8
GDP per capita ($2010 thousand)	6.3	7.2	8.2	10	14	17	20	1.4	2.0	1.8	1.9
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.9	2.0	2.0	0.4	0.4	0.1	0.2
Primary energy consumption per GDP[*2]	257	232	201	178	142	119	100	-1.0	-1.6	-1.7	-1.7
CO_2 emissions per GDP[*3]	634	541	463	418	322	264	218	-1.0	-1.9	-1.9	-1.9
CO_2 per primary energy consumption[*4]	2.5	2.3	2.3	2.4	2.3	2.2	2.2	0.0	-0.3	-0.2	-0.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A21 | Asia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total*1	1,439	2,110	2,887	5,497	7,327	8,336	8,987	100	100	100	3.8	2.1	1.0	1.5
Coal	466	787	1,036	2,685	3,238	3,505	3,557	37	49	40	4.8	1.3	0.5	0.8
Oil	477	618	916	1,367	1,819	2,052	2,207	29	25	25	3.1	2.1	1.0	1.4
Natural gas	51	116	233	567	988	1,274	1,524	5.5	10	17	6.3	4.1	2.2	3.0
Nuclear	25	77	132	122	271	338	404	3.6	2.2	4.5	1.8	5.9	2.0	3.6
Hydro	20	32	41	138	182	205	221	1.5	2.5	2.5	5.8	2.0	1.0	1.4
Geothermal	2.6	8.2	23	40	93	119	145	0.4	0.7	1.6	6.3	6.3	2.2	3.9
Solar, wind, etc.	-	1.2	2.1	62	180	264	344	0.1	1.1	3.8	16.2	7.9	3.3	5.2
Biomass and waste	397	471	503	517	554	579	584	22	9.4	6.5	0.4	0.5	0.3	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,129	1,556	1,991	3,709	4,783	5,412	5,887	100	100	100	3.4	1.8	1.0	1.4
Industry	383	514	647	1,511	1,789	1,959	2,086	33	41	35	4.2	1.2	0.8	1.0
Transport	124	184	318	661	969	1,120	1,226	12	18	21	5.1	2.8	1.2	1.8
Buildings, etc.	569	741	842	1,162	1,525	1,750	1,935	48	31	33	1.7	2.0	1.2	1.5
Non-energy use	54	117	185	375	499	583	640	7.5	10	11	4.6	2.1	1.3	1.6
Coal	301	424	373	899	906	901	873	27	24	15	2.9	0.1	-0.2	-0.1
Oil	326	459	734	1,204	1,634	1,859	2,017	29	32	34	3.8	2.2	1.1	1.5
Natural gas	21	47	88	266	463	574	653	3.0	7.2	11	6.9	4.0	1.7	2.7
Electricity	88	156	278	784	1,217	1,512	1,793	10	21	30	6.4	3.2	2.0	2.5
Heat	7.5	14	30	96	110	118	120	0.9	2.6	2.0	7.6	1.0	0.4	0.7
Hydrogen	-	-	-	-	0.2	0.5	0.5	-	-	-	n.a.	n.a.	3.7	n.a.
Renewables	386	456	488	459	452	447	431	29	12	7.3	0.0	-0.1	-0.2	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,196	2,240	3,983	10,768	16,728	20,542	23,994	100	100	100	6.2	3.2	1.8	2.4
Coal	298	869	1,990	6,443	8,928	10,379	11,496	39	60	48	8.0	2.4	1.3	1.7
Oil	476	434	390	233	209	183	140	19	2.2	0.6	-2.4	-0.8	-2.0	-1.5
Natural gas	90	237	559	1,340	2,299	3,156	4,119	11	12	17	6.9	3.9	3.0	3.4
Nuclear	97	294	505	468	1,041	1,296	1,552	13	4.3	6.5	1.8	5.9	2.0	3.6
Hydro	232	369	478	1,603	2,118	2,382	2,565	16	15	11	5.8	2.0	1.0	1.4
Geothermal	3.0	8.4	20	24	60	77	94	0.4	0.2	0.4	4.2	6.7	2.2	4.1
Solar PV	-	0.1	0.6	152	708	1,123	1,533	-	1.4	6.4	34.4	11.6	3.9	7.0
Wind	-	-	2.4	294	993	1,458	1,892	-	2.7	7.9	41.7	9.1	3.3	5.6
CSP and marine	-	-	-	0.5	7.5	14	26	-	-	0.1	18.2	20.8	6.4	12.1
Biomass and waste	-	9.5	17	187	341	452	554	0.4	1.7	2.3	12.1	4.4	2.5	3.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	23	23	23	23	0.9	0.2	0.1	0.6	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	4,441	7,560	11,025	23,349	42,947	61,820	81,967	4.4	4.4	3.3	3.8
Population (million)	2,440	2,933	3,410	4,035	4,439	4,601	4,665	1.2	0.7	0.2	0.4
CO_2 emissions (Mt)	3,105	4,632	6,720	14,795	18,891	21,064	22,176	4.6	1.8	0.8	1.2
GDP per capita ($2010 thousand)	1.8	2.6	3.2	5.8	9.7	13	18	3.2	3.7	3.0	3.3
Primary energy consump. per capita (toe)	0.6	0.7	0.8	1.4	1.7	1.8	1.9	2.5	1.4	0.8	1.0
Primary energy consumption per GDP*2	324	279	262	235	171	135	110	-0.7	-2.3	-2.2	-2.2
CO_2 emissions per GDP*3	699	613	609	634	440	341	271	0.1	-2.6	-2.4	-2.5
CO_2 per primary energy consumption*4	2.2	2.2	2.3	2.7	2.6	2.5	2.5	0.8	-0.3	-0.2	-0.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A22 | China [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	598	874	1,130	2,958	3,658	3,915	3,873	100	100	100	4.8	1.5	0.3	0.8
Coal	313	531	665	1,916	2,035	2,014	1,817	61	65	47	5.1	0.4	-0.6	-0.2
Oil	89	119	221	545	732	774	743	14	18	19	6.0	2.1	0.1	0.9
Natural gas	12	13	21	171	370	476	554	1.5	5.8	14	10.5	5.7	2.0	3.5
Nuclear	-	-	4.4	56	149	200	249	-	1.9	6.4	n.a.	7.3	2.6	4.5
Hydro	5.0	11	19	100	122	132	135	1.2	3.4	3.5	8.9	1.4	0.5	0.9
Geothermal	-	-	1.7	9.4	12	15	16	-	0.3	0.4	n.a.	2.0	1.2	1.5
Solar, wind, etc.	-	-	1.0	49	133	186	231	-	1.7	6.0	32.4	7.3	2.8	4.7
Biomass and waste	180	200	198	113	106	121	130	23	3.8	3.3	-2.2	-0.5	1.0	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	487	658	781	1,969	2,365	2,517	2,536	100	100	100	4.3	1.3	0.3	0.7
Industry	181	234	302	994	998	986	967	36	50	38	5.7	0.0	-0.2	-0.1
Transport	22	30	84	297	465	501	484	4.6	15	19	9.2	3.3	0.2	1.4
Buildings, etc.	274	351	338	516	686	778	816	53	26	32	1.5	2.1	0.9	1.4
Non-energy use	10	43	57	162	215	252	269	6.5	8.2	11	5.3	2.0	1.1	1.5
Coal	214	311	274	710	620	558	488	47	36	19	3.2	-1.0	-1.2	-1.1
Oil	59	85	180	495	673	712	685	13	25	27	7.0	2.2	0.1	1.0
Natural gas	6.4	8.9	12	113	214	264	294	1.3	5.7	12	10.3	4.7	1.6	2.8
Electricity	21	39	89	445	655	769	848	5.9	23	33	9.8	2.8	1.3	1.9
Heat	7.4	13	26	90	103	111	113	2.0	4.6	4.5	7.7	1.0	0.4	0.7
Hydrogen	-	-	-	-	0.2	0.3	0.3	-	-	-	n.a.	n.a.	3.1	n.a.
Renewables	180	200	199	117	99	103	107	30	5.9	4.2	-2.1	-1.2	0.4	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	301	621	1,356	6,187	9,019	10,463	11,388	100	100	100	9.2	2.7	1.2	1.8
Coal	159	441	1,060	4,242	5,157	5,444	5,374	71	69	47	9.1	1.4	0.2	0.7
Oil	82	50	47	10	10.0	8.2	5.7	8.1	0.2	0.1	-5.9	-0.3	-2.8	-1.7
Natural gas	0.7	2.8	5.8	170	535	773	1,020	0.4	2.8	9.0	17.2	8.5	3.3	5.4
Nuclear	-	-	17	213	573	766	955	-	3.4	8.4	n.a.	7.3	2.6	4.5
Hydro	58	127	222	1,163	1,414	1,531	1,574	20	19	14	8.9	1.4	0.5	0.9
Geothermal	-	0.1	0.1	0.1	0.4	0.4	0.5	-	-	-	3.1	8.2	1.3	4.1
Solar PV	-	-	-	75	388	573	734	-	1.2	6.4	50.0	12.4	3.2	6.9
Wind	-	-	0.6	237	802	1,169	1,474	-	3.8	13	56.7	9.1	3.1	5.5
CSP and marine	-	-	-	-	1.0	3.7	8.0	-	-	0.1	6.9	26.2	10.7	16.9
Biomass and waste	-	-	2.4	76	139	195	244	-	1.2	2.1	n.a.	4.4	2.8	3.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	341	830	2,237	9,504	20,603	31,022	40,505	9.8	5.7	3.4	4.4
Population (million)	981	1,135	1,263	1,379	1,416	1,393	1,341	0.8	0.2	-0.3	-0.1
CO_2 emissions (Mt)	1,392	2,136	3,126	9,015	10,267	10,433	9,706	5.7	0.9	-0.3	0.2
GDP per capita ($2010 thousand)	0.3	0.7	1.8	6.9	15	22	30	9.0	5.5	3.7	4.4
Primary energy consump. per capita (toe)	0.6	0.8	0.9	2.1	2.6	2.8	2.9	4.0	1.3	0.6	0.9
Primary energy consumption per GDP[*2]	1,752	1,053	505	311	178	126	96	-4.6	-3.9	-3.0	-3.4
CO_2 emissions per GDP[*3]	4,079	2,575	1,398	949	498	336	240	-3.8	-4.5	-3.6	-4.0
CO_2 per primary energy consumption[*4]	2.3	2.4	2.8	3.0	2.8	2.7	2.5	0.9	-0.6	-0.6	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A23 | India [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	200	306	441	862	1,499	1,943	2,357	100	100	100	4.1	4.0	2.3	3.0
Coal	44	93	146	380	694	892	1,068	30	44	45	5.6	4.4	2.2	3.1
Oil	33	61	112	217	390	516	633	20	25	27	5.0	4.3	2.5	3.2
Natural gas	1.3	11	23	47	127	197	270	3.5	5.5	11	5.9	7.4	3.8	5.3
Nuclear	0.8	1.6	4.4	9.9	30	47	63	0.5	1.1	2.7	7.3	8.4	3.7	5.6
Hydro	4.0	6.2	6.4	12	24	31	38	2.0	1.4	1.6	2.5	5.2	2.4	3.5
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	0.2	5.8	31	51	74	-	0.7	3.1	27.5	12.8	4.4	7.8
Biomass and waste	116	133	149	192	203	209	210	44	22	8.9	1.4	0.4	0.2	0.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	174	243	314	572	971	1,261	1,538	100	100	100	3.4	3.9	2.3	2.9
Industry	41	67	83	193	364	473	557	27	34	36	4.2	4.7	2.1	3.2
Transport	17	21	32	90	168	234	299	8.5	16	19	5.8	4.6	2.9	3.6
Buildings, etc.	110	142	172	243	351	440	545	59	43	35	2.1	2.7	2.2	2.4
Non-energy use	5.7	13	27	46	88	115	137	5.5	8.1	8.9	4.9	4.7	2.3	3.2
Coal	25	38	33	99	177	222	252	16	17	16	3.7	4.3	1.8	2.8
Oil	27	50	94	182	342	461	575	21	32	37	5.1	4.6	2.6	3.4
Natural gas	0.7	5.6	9.7	32	74	105	128	2.3	5.6	8.3	6.9	6.2	2.8	4.1
Electricity	7.8	18	32	95	219	321	439	7.6	17	29	6.5	6.1	3.5	4.6
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	0.1	0.1	-	-	-	n.a.	n.a.	7.0	n.a.
Renewables	114	130	144	164	158	153	144	54	29	9.4	0.9	-0.2	-0.5	-0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	120	293	570	1,478	3,285	4,628	6,086	100	100	100	6.4	5.9	3.1	4.3
Coal	61	192	390	1,105	2,184	2,936	3,710	65	75	61	7.0	5.0	2.7	3.6
Oil	8.8	13	29	23	31	29	18	4.5	1.6	0.3	2.2	2.1	-2.6	-0.7
Natural gas	0.6	10.0	56	71	256	462	744	3.4	4.8	12	7.9	9.6	5.5	7.1
Nuclear	3.0	6.1	17	38	117	182	241	2.1	2.6	4.0	7.3	8.4	3.7	5.6
Hydro	47	72	74	138	280	364	448	24	9.3	7.4	2.5	5.2	2.4	3.5
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	14	176	307	440	-	1.0	7.2	n.a.	19.7	4.7	10.6
Wind	-	-	1.7	45	151	228	330	-	3.0	5.4	32.1	9.1	4.0	6.0
CSP and marine	-	-	-	-	3.2	5.9	9.5	-	-	0.2	n.a.	n.a.	5.6	n.a.
Biomass and waste	-	-	1.3	44	86	115	145	-	3.0	2.4	n.a.	5.0	2.6	3.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	271	465	800	2,456	6,243	10,407	16,104	6.6	6.9	4.9	5.7
Population (million)	697	870	1,053	1,324	1,513	1,605	1,659	1.6	1.0	0.5	0.7
CO_2 emissions (Mt)	258	529	885	2,078	3,921	5,180	6,343	5.4	4.6	2.4	3.3
GDP per capita ($2010 thousand)	0.4	0.5	0.8	1.9	4.1	6.5	9.7	4.9	5.9	4.4	5.0
Primary energy consump. per capita (toe)	0.3	0.4	0.4	0.7	1.0	1.2	1.4	2.4	3.0	1.8	2.3
Primary energy consumption per GDP[*2]	739	658	551	351	240	187	146	-2.4	-2.7	-2.4	-2.5
CO_2 emissions per GDP[*3]	953	1,138	1,106	846	628	498	394	-1.1	-2.1	-2.3	-2.2
CO_2 per primary energy consumption[*4]	1.3	1.7	2.0	2.4	2.6	2.7	2.7	1.3	0.6	0.1	0.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A24 | Japan [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	345	438	518	426	420	394	367	100	100	100	-0.1	-0.1	-0.7	-0.4
Coal	60	76	97	114	103	99	89	17	27	24	1.6	-0.8	-0.7	-0.7
Oil	234	250	255	177	144	126	110	57	42	30	-1.3	-1.4	-1.4	-1.4
Natural gas	21	44	66	102	96	91	83	10	24	23	3.3	-0.4	-0.7	-0.6
Nuclear	22	53	84	4.7	40	35	34	12	1.1	9.4	-8.9	16.4	-0.7	6.0
Hydro	7.6	7.6	7.3	6.8	7.7	7.8	7.9	1.7	1.6	2.1	-0.4	0.9	0.1	0.4
Geothermal	0.8	1.6	3.1	2.3	5.2	8.2	11	0.4	0.5	2.9	1.5	5.8	3.6	4.5
Solar, wind, etc.	-	1.2	0.8	5.1	7.7	11	14	0.3	1.2	3.8	5.8	2.9	3.0	3.0
Biomass and waste	-	4.6	4.9	14	17	18	18	1.0	3.2	4.9	4.4	1.3	0.5	0.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	232	288	331	294	277	261	245	100	100	100	0.1	-0.4	-0.6	-0.5
Industry	91	106	97	82	79	77	75	37	28	30	-1.0	-0.3	-0.3	-0.3
Transport	54	68	86	72	58	51	46	24	24	19	0.2	-1.4	-1.2	-1.3
Buildings, etc.	58	78	106	104	104	97	91	27	35	37	1.1	0.0	-0.7	-0.4
Non-energy use	28	36	41	37	36	35	34	12	13	14	0.2	-0.2	-0.4	-0.3
Coal	25	27	21	21	19	18	17	9.5	7.3	6.8	-0.9	-0.7	-0.8	-0.7
Oil	157	177	202	150	126	112	100	61	51	41	-0.6	-1.2	-1.1	-1.2
Natural gas	5.8	15	22	32	36	34	33	5.1	11	13	3.0	0.8	-0.4	0.0
Electricity	44	65	81	83	89	90	89	23	28	36	1.0	0.5	0.0	0.2
Heat	0.1	0.2	0.5	0.5	0.4	0.4	0.3	0.1	0.2	0.1	3.7	-1.2	-1.3	-1.3
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	-1.4	n.a.
Renewables	-	3.9	3.8	6.7	6.7	6.4	6.1	1.4	2.3	2.5	2.1	0.0	-0.4	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	573	861	1,058	1,052	1,125	1,130	1,112	100	100	100	0.8	0.5	-0.1	0.2
Coal	55	123	230	349	315	314	295	14	33	26	4.1	-0.7	-0.3	-0.5
Oil	265	248	140	84	47	27	8.2	29	8.0	0.7	-4.1	-4.2	-8.3	-6.6
Natural gas	81	168	248	406	360	355	330	20	39	30	3.5	-0.9	-0.4	-0.6
Nuclear	83	202	322	18	152	133	132	24	1.7	12	-8.9	16.4	-0.7	6.0
Hydro	88	88	84	79	89	91	91	10	7.5	8.2	-0.4	0.9	0.1	0.4
Geothermal	0.9	1.7	3.3	2.5	5.8	9.4	12	0.2	0.2	1.1	1.4	6.2	3.7	4.7
Solar PV	-	0.1	0.4	51	72	102	131	-	4.8	12	29.1	2.5	3.1	2.8
Wind	-	-	0.1	6.0	16	22	31	-	0.6	2.7	n.a.	7.1	3.4	4.9
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	8.9	10	34	47	55	61	1.0	3.2	5.5	5.2	2.4	1.3	1.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	21	21	21	21	2.3	2.0	1.9	0.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	2,977	4,683	5,349	6,053	6,808	7,353	7,885	1.0	0.8	0.7	0.8
Population (million)	117	124	127	127	121	115	108	0.1	-0.4	-0.6	-0.5
CO_2 emissions (Mt)	908	1,046	1,145	1,138	984	902	802	0.3	-1.0	-1.0	-1.0
GDP per capita ($2010 thousand)	25	38	42	48	56	64	73	0.9	1.2	1.3	1.3
Primary energy consump. per capita (toe)	3.0	3.5	4.1	3.4	3.5	3.4	3.4	-0.2	0.3	-0.1	0.0
Primary energy consumption per GDP[*2]	116	94	97	70	62	54	46	-1.1	-0.9	-1.4	-1.2
CO_2 emissions per GDP[*3]	305	223	214	188	144	123	102	-0.7	-1.9	-1.7	-1.8
CO_2 per primary energy consumption[*4]	2.6	2.4	2.2	2.7	2.3	2.3	2.2	0.4	-0.9	-0.3	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A25 | Korea [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total*1	41	93	188	282	307	304	287	100	100	100	4.4	0.6	-0.3	0.0
Coal	14	25	42	81	89	88	81	27	29	28	4.6	0.6	-0.4	0.0
Oil	27	50	99	110	113	109	100	54	39	35	3.1	0.2	-0.6	-0.3
Natural gas	-	2.7	17	41	55	63	67	2.9	15	24	11.0	2.1	1.0	1.5
Nuclear	0.9	14	28	42	38	31	23	15	15	8.0	4.4	-0.8	-2.5	-1.8
Hydro	0.2	0.5	0.3	0.2	0.3	0.3	0.3	0.6	0.1	0.1	-3.0	2.0	0.0	0.8
Geothermal	-	-	-	0.2	0.2	0.2	0.2	-	0.1	0.1	n.a.	1.6	0.4	0.9
Solar, wind, etc.	-	-	-	0.8	2.6	3.9	5.7	-	0.3	2.0	18.1	9.2	4.1	6.1
Biomass and waste	-	0.7	1.4	6.4	8.7	8.8	8.4	0.8	2.3	2.9	8.7	2.2	-0.2	0.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	31	65	127	179	196	197	189	100	100	100	4.0	0.7	-0.2	0.2
Industry	10	19	38	48	52	52	50	30	27	26	3.6	0.6	-0.2	0.1
Transport	4.8	15	26	35	37	35	31	22	20	16	3.4	0.4	-0.9	-0.3
Buildings, etc.	13	24	37	46	52	53	53	38	26	28	2.5	0.8	0.1	0.4
Non-energy use	3.1	6.7	25	50	55	56	56	10	28	29	8.0	0.7	0.0	0.3
Coal	9.7	12	9.1	9.4	8.4	7.5	6.4	18	5.3	3.4	-0.8	-0.8	-1.4	-1.1
Oil	19	44	80	94	98	93	86	67	53	46	3.0	0.3	-0.6	-0.2
Natural gas	-	0.7	11	22	26	27	27	1.0	12	14	14.3	1.4	0.2	0.7
Electricity	2.8	8.1	23	44	54	58	60	13	25	32	6.8	1.4	0.6	0.9
Heat	-	-	3.3	4.8	4.8	4.8	4.5	-	2.7	2.4	n.a.	0.1	-0.4	-0.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	2.6	n.a.
Renewables	-	0.7	1.3	4.4	5.2	5.1	4.7	1.1	2.5	2.5	7.1	1.2	-0.6	0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	37	105	289	559	677	736	761	100	100	100	6.6	1.4	0.6	0.9
Coal	2.5	18	111	235	275	293	288	17	42	38	10.5	1.1	0.2	0.6
Oil	29	19	35	18	16	13	7.9	18	3.2	1.0	-0.2	-0.7	-3.5	-2.4
Natural gas	-	9.6	29	127	194	248	291	9.1	23	38	10.4	3.1	2.0	2.5
Nuclear	3.5	53	109	162	146	117	88	50	29	12	4.4	-0.8	-2.5	-1.8
Hydro	2.0	6.4	4.0	2.8	3.7	3.7	3.7	6.0	0.5	0.5	-3.0	2.0	0.0	0.8
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	5.1	22	32	45	-	0.9	5.9	38.9	10.8	3.7	6.6
Wind	-	-	-	1.7	4.9	8.3	14	-	0.3	1.8	n.a.	8.0	5.2	6.4
CSP and marine	-	-	-	0.5	3.2	4.7	8.0	-	0.1	1.1	n.a.	14.2	4.7	8.5
Biomass and waste	-	-	0.1	6.4	12	13	14	-	1.1	1.9	n.a.	4.5	0.9	2.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	1.3	1.3	1.3	1.3	-	0.2	0.2	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	141	363	710	1,305	1,873	2,278	2,624	5.0	2.6	1.7	2.1
Population (million)	38	43	47	51	53	53	51	0.7	0.3	-0.2	0.0
CO_2 emissions (Mt)	112	215	414	601	659	660	621	4.0	0.7	-0.3	0.1
GDP per capita ($2010 thousand)	3.7	8.5	15	25	35	43	52	4.3	2.3	1.9	2.1
Primary energy consump. per capita (toe)	1.1	2.2	4.0	5.5	5.8	5.8	5.6	3.7	0.3	-0.1	0.1
Primary energy consumption per GDP*2	292	256	265	216	164	134	109	-0.6	-2.0	-2.0	-2.0
CO_2 emissions per GDP*3	793	593	583	461	352	290	237	-1.0	-1.9	-2.0	-1.9
CO_2 per primary energy consumption*4	2.7	2.3	2.2	2.1	2.1	2.2	2.2	-0.3	0.0	0.1	0.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A26 | Chinese Taipei [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	28	48	85	110	111	110	105	100	100	100	3.3	0.1	-0.3	-0.1
Coal	3.9	11	30	41	42	39	33	24	37	32	5.0	0.2	-1.2	-0.6
Oil	20	26	38	43	41	39	36	54	39	35	2.0	-0.2	-0.7	-0.5
Natural gas	1.6	1.4	5.6	15	22	25	28	2.9	14	27	9.7	2.6	1.1	1.7
Nuclear	2.1	8.6	10	8.2	-	-	-	18	7.5	-	-0.1	-100	n.a.	-100
Hydro	0.3	0.5	0.4	0.6	0.4	0.4	0.4	1.1	0.5	0.4	0.1	-2.2	0.0	-0.9
Geothermal	-	-	-	-	-	-	-	-	-	-	-100	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	0.1	0.3	1.3	2.2	3.1	-	0.3	3.0	11.8	10.6	4.3	6.8
Biomass and waste	-	-	0.6	1.5	3.3	3.7	3.7	-	1.4	3.5	n.a.	6.0	0.5	2.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	19	29	49	70	72	72	71	100	100	100	3.4	0.2	-0.1	0.0
Industry	10	12	19	23	24	24	24	42	33	33	2.5	0.2	-0.1	0.0
Transport	2.9	6.6	12	13	12	11	8.9	22	18	13	2.6	-0.5	-1.5	-1.1
Buildings, etc.	3.6	6.5	10	12	14	14	15	22	17	21	2.5	0.7	0.6	0.6
Non-energy use	2.0	4.0	7.8	22	23	23	23	14	31	33	6.8	0.3	0.1	0.2
Coal	2.2	3.6	5.0	8.5	8.1	7.5	6.8	12	12	9.6	3.4	-0.4	-0.8	-0.7
Oil	12	18	28	38	37	35	33	62	54	46	2.9	-0.2	-0.6	-0.4
Natural gas	1.4	0.9	1.6	3.0	3.9	4.2	4.2	3.0	4.3	5.9	4.9	1.9	0.3	1.0
Electricity	3.2	6.6	14	20	23	25	26	22	29	37	4.4	0.9	0.7	0.8
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	0.5	n.a.
Renewables	-	-	0.1	0.2	0.4	0.5	0.5	0.1	0.3	0.7	9.8	4.4	1.8	2.8

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	43	88	181	261	295	319	338	100	100	100	4.2	0.9	0.7	0.8
Coal	6.0	24	88	122	134	128	118	28	47	35	6.4	0.7	-0.6	-0.1
Oil	26	23	30	11	11	8.5	6.1	26	4.3	1.8	-2.8	-0.5	-2.7	-1.8
Natural gas	-	1.2	17	83	124	146	166	1.4	32	49	17.5	2.9	1.5	2.0
Nuclear	8.2	33	39	32	-	-	-	37	12	-	-0.1	-100	n.a.	-100
Hydro	2.9	6.4	4.6	6.6	4.8	4.8	4.8	7.2	2.5	1.4	0.1	-2.2	0.0	-0.9
Geothermal	-	-	-	-	-	-	-	-	-	-	-100	n.a.	n.a.	n.a.
Solar PV	-	-	-	1.1	6.1	10	14	-	0.4	4.3	n.a.	12.7	4.4	7.8
Wind	-	-	-	1.5	8.3	14	20	-	0.6	5.9	n.a.	13.2	4.5	8.0
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	1.7	3.5	7.3	8.3	8.8	-	1.4	2.6	n.a.	5.4	0.9	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	70	155	297	514	684	814	929	4.7	2.1	1.5	1.8
Population (million)	18	20	22	24	24	24	23	0.6	0.2	-0.3	-0.1
CO_2 emissions (Mt)	71	110	214	261	276	263	239	3.4	0.4	-0.7	-0.3
GDP per capita ($2010 thousand)	3.9	7.6	13	22	28	34	41	4.1	1.9	1.8	1.9
Primary energy consump. per capita (toe)	1.6	2.3	3.8	4.7	4.6	4.6	4.6	2.7	-0.1	0.0	0.0
Primary energy consumption per GDP[*2]	396	308	286	213	162	135	112	-1.4	-1.9	-1.8	-1.9
CO_2 emissions per GDP[*3]	1,008	706	722	508	404	323	257	-1.3	-1.6	-2.2	-2.0
CO_2 per primary energy consumption[*4]	2.5	2.3	2.5	2.4	2.5	2.4	2.3	0.1	0.3	-0.4	-0.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A27 | ASEAN [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	142	233	379	643	1,011	1,270	1,514	100	100	100	4.0	3.3	2.0	2.6
Coal	3.6	13	32	120	233	316	395	5.4	19	26	9.1	4.8	2.7	3.6
Oil	58	89	153	220	314	386	461	38	34	30	3.6	2.6	1.9	2.2
Natural gas	8.6	30	74	139	225	285	339	13	22	22	6.1	3.5	2.1	2.7
Nuclear	-	-	-	-	-	12	21	-	-	1.4	n.a.	n.a.	n.a.	n.a.
Hydro	0.8	2.3	4.1	11	18	20	22	1.0	1.7	1.5	6.1	3.5	1.1	2.1
Geothermal	1.8	6.6	18	28	75	96	117	2.8	4.3	7.8	5.7	7.3	2.3	4.3
Solar, wind, etc.	-	-	-	0.6	3.8	8.1	13	-	0.1	0.9	n.a.	14.8	6.3	9.8
Biomass and waste	70	93	98	123	140	144	141	40	19	9.3	1.1	1.0	0.0	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	112	173	270	451	659	812	960	100	100	100	3.7	2.7	1.9	2.2
Industry	22	43	75	129	208	267	317	25	29	33	4.3	3.5	2.1	2.7
Transport	17	32	61	122	176	220	273	19	27	28	5.2	2.7	2.2	2.4
Buildings, etc.	71	87	113	148	199	230	257	50	33	27	2.1	2.1	1.3	1.6
Non-energy use	2.4	11	21	52	76	95	114	6.3	12	12	6.2	2.7	2.1	2.3
Coal	2.1	6.1	13	35	53	64	72	3.5	7.8	7.5	7.0	3.0	1.6	2.1
Oil	41	67	123	204	292	362	435	38	45	45	4.4	2.6	2.0	2.3
Natural gas	2.5	7.5	17	37	66	85	100	4.4	8.2	10	6.3	4.2	2.1	3.0
Electricity	4.7	11	28	73	139	194	253	6.4	16	26	7.5	4.7	3.1	3.7
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	0.1	-	-	-	n.a.	n.a.	5.8	n.a.
Renewables	61	82	89	102	109	107	99	47	23	10	0.8	0.5	-0.5	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	62	154	370	926	1,780	2,493	3,251	100	100	100	7.1	4.8	3.1	3.8
Coal	3.0	28	79	339	785	1,157	1,566	18	37	48	10.1	6.2	3.5	4.6
Oil	47	66	72	25	23	22	14	43	2.7	0.4	-3.7	-0.5	-2.4	-1.6
Natural gas	0.7	26	154	383	617	808	1,019	17	41	31	10.9	3.5	2.5	2.9
Nuclear	-	-	-	-	-	44	81	-	-	2.5	n.a.	n.a.	n.a.	n.a.
Hydro	9.8	27	47	128	208	238	259	18	14	8.0	6.1	3.5	1.1	2.1
Geothermal	2.1	6.6	16	22	54	67	81	4.3	2.3	2.5	4.7	6.7	2.1	3.9
Solar PV	-	-	-	4.9	38	83	136	-	0.5	4.2	n.a.	15.7	6.6	10.2
Wind	-	-	-	1.5	6.3	11	16	-	0.2	0.5	n.a.	10.7	4.8	7.2
CSP and marine	-	-	-	-	0.1	0.2	0.3	-	-	-	n.a.	n.a.	8.3	n.a.
Biomass and waste	-	0.6	1.0	23	47	63	78	0.4	2.5	2.4	15.1	5.3	2.5	3.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

								1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	2016	2030	2050	2050
GDP ($2010 billion)	440	741	1,180	2,607	5,042	7,503	10,546	5.0	4.8	3.8	4.2
Population (million)	346	430	506	618	700	740	765	1.4	0.9	0.4	0.6
CO_2 emissions (Mt)	188	348	676	1,298	2,158	2,793	3,403	5.2	3.7	2.3	2.9
GDP per capita ($2010 thousand)	1.3	1.7	2.3	4.2	7.2	10	14	3.5	3.9	3.3	3.5
Primary energy consump. per capita (toe)	0.4	0.5	0.7	1.0	1.4	1.7	2.0	2.5	2.4	1.6	1.9
Primary energy consumption per GDP[*2]	323	314	322	247	201	169	144	-0.9	-1.5	-1.7	-1.6
CO_2 emissions per GDP[*3]	426	469	573	498	428	372	323	0.2	-1.1	-1.4	-1.3
CO_2 per primary energy consumption[*4]	1.3	1.5	1.8	2.0	2.1	2.2	2.2	1.2	0.4	0.3	0.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A28 | Indonesia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	56	99	156	230	390	497	591	100	100	100	3.3	3.8	2.1	2.8
Coal	0.2	3.5	12	43	88	124	158	3.6	19	27	10.1	5.2	3.0	3.9
Oil	20	33	58	70	104	127	147	34	31	25	2.9	2.8	1.8	2.2
Natural gas	5.0	16	27	39	77	108	134	16	17	23	3.5	5.0	2.8	3.7
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.5	0.9	1.7	1.7	1.8	2.0	0.5	0.7	0.3	4.8	-0.1	1.0	0.6
Geothermal	-	1.9	8.4	18	58	76	96	2.0	8.0	16	9.0	8.6	2.6	5.0
Solar, wind, etc.	-	-	-	-	-	0.1	0.2	-	-	-	n.a.	24.2	8.0	14.4
Biomass and waste	30	44	50	58	62	59	54	44	25	9.1	1.1	0.5	-0.7	-0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	50	80	120	165	241	295	342	100	100	100	2.8	2.8	1.8	2.2
Industry	6.7	18	30	39	65	85	103	23	24	30	3.0	3.7	2.4	2.9
Transport	6.0	11	21	47	70	89	109	13	29	32	5.9	2.9	2.2	2.5
Buildings, etc.	36	44	59	71	95	106	114	55	43	33	1.9	2.1	0.9	1.4
Non-energy use	1.2	7.4	9.8	7.4	11	14	16	9.2	4.5	4.8	0.0	3.1	1.9	2.4
Coal	0.1	2.3	4.7	9.5	15	19	23	2.8	5.8	6.8	5.7	3.3	2.2	2.7
Oil	17	27	48	67	98	121	142	34	41	41	3.5	2.8	1.8	2.2
Natural gas	2.4	6.0	12	13	28	40	48	7.5	8.2	14	3.2	5.4	2.7	3.8
Electricity	0.6	2.4	6.8	19	39	58	78	3.0	11	23	8.1	5.5	3.5	4.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	5.4	n.a.
Renewables	29	42	49	56	60	57	52	53	34	15	1.1	0.5	-0.7	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	7.5	33	93	249	525	773	1,026	100	100	100	8.1	5.5	3.4	4.3
Coal	-	9.8	34	135	309	465	627	30	54	61	10.6	6.1	3.6	4.6
Oil	6.2	15	18	16	14	14	9.4	47	6.3	0.9	0.1	-0.8	-2.0	-1.5
Natural gas	-	0.7	26	66	146	222	302	2.2	26	29	18.9	5.9	3.7	4.6
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	1.3	5.7	10	19	19	21	24	17	7.8	2.3	4.8	-0.1	1.0	0.6
Geothermal	-	1.1	4.9	11	34	44	56	3.4	4.3	5.4	9.0	8.6	2.6	5.0
Solar PV	-	-	-	-	0.5	1.5	2.5	-	-	0.2	n.a.	26.0	8.0	15.1
Wind	-	-	-	-	-	0.1	0.1	-	-	-	n.a.	11.6	6.4	8.5
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	1.8	3.4	4.6	5.8	-	0.7	0.6	n.a.	4.7	2.6	3.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	182	310	453	1,038	2,138	3,351	4,849	4.8	5.3	4.2	4.6
Population (million)	147	181	212	261	296	313	322	1.4	0.9	0.4	0.6
CO_2 emissions (Mt)	64	133	255	455	811	1,089	1,339	4.8	4.2	2.5	3.2
GDP per capita ($2010 thousand)	1.2	1.7	2.1	4.0	7.2	11	15	3.3	4.4	3.7	4.0
Primary energy consump. per capita (toe)	0.4	0.5	0.7	0.9	1.3	1.6	1.8	1.9	2.9	1.7	2.2
Primary energy consumption per GDP[*2]	307	318	343	222	182	148	122	-1.4	-1.4	-2.0	-1.7
CO_2 emissions per GDP[*3]	352	431	563	439	379	325	276	0.1	-1.0	-1.6	-1.4
CO_2 per primary energy consumption[*4]	1.1	1.4	1.6	2.0	2.1	2.2	2.3	1.5	0.4	0.4	0.4

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A29 | Malaysia [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	12	22	49	89	125	146	161	100	100	100	5.5	2.4	1.3	1.8
Coal	0.1	1.4	2.3	19	33	39	43	6.2	21	27	10.6	4.2	1.3	2.5
Oil	7.9	11	19	31	37	40	42	53	35	26	3.9	1.3	0.6	0.9
Natural gas	2.2	6.8	25	36	49	57	66	31	40	41	6.6	2.3	1.5	1.8
Nuclear	-	-	-	-	-	3.7	3.7	-	-	2.3	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.3	0.6	1.7	2.4	2.8	3.1	1.6	1.9	1.9	6.4	2.4	1.3	1.7
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	-	0.2	0.4	0.6	-	-	0.3	n.a.	14.9	5.7	9.4
Biomass and waste	1.6	1.9	1.9	1.9	2.6	2.9	3.2	8.5	2.2	2.0	0.2	2.2	0.9	1.4

Final energy consumption

	Mtoe							Shares (%)						
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total	7.2	14	30	56	76	87	96	100	100	100	5.5	2.2	1.2	1.6
Industry	3.1	5.6	12	16	26	32	37	40	29	38	4.2	3.4	1.7	2.4
Transport	2.1	4.9	11	22	24	25	25	35	39	26	5.9	0.8	0.2	0.4
Buildings, etc.	1.7	2.6	5.0	9.3	13	15	17	19	17	18	5.0	2.3	1.6	1.9
Non-energy use	0.3	0.8	2.2	8.7	12	15	17	6.0	16	18	9.4	2.5	1.6	2.0
Coal	0.1	0.5	1.0	1.8	2.4	2.8	3.0	3.7	3.2	3.1	4.9	2.2	1.1	1.5
Oil	5.3	9.3	18	28	34	36	38	67	50	40	4.4	1.3	0.6	0.9
Natural gas	-	1.1	3.9	12	18	21	23	7.9	22	24	9.8	2.8	1.2	1.8
Electricity	0.7	1.7	5.3	12	20	26	31	12	22	32	7.9	3.5	2.2	2.7
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	3.5	n.a.
Renewables	1.0	1.3	1.3	1.2	1.2	1.2	1.1	9.1	2.2	1.2	-0.1	-0.4	-0.2	-0.3

Electricity generation

	(TWh)							Shares (%)						
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total	10	23	69	157	257	330	398	100	100	100	7.7	3.6	2.2	2.8
Coal	-	2.9	7.7	69	141	173	198	13	44	50	12.9	5.2	1.7	3.1
Oil	8.5	11	3.6	1.2	1.1	0.7	-	46	0.8	-	-8.1	-0.3	-100	-100
Natural gas	0.1	5.5	51	65	82	101	138	24	42	35	9.9	1.7	2.6	2.2
Nuclear	-	-	-	-	-	14	14	-	-	3.5	n.a.	n.a.	n.a.	n.a.
Hydro	1.4	4.0	7.0	20	28	32	36	17	13	9.1	6.4	2.4	1.3	1.7
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	0.3	2.2	4.3	6.5	-	0.2	1.6	n.a.	14.9	5.7	9.4
Wind	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	0.8	3.4	4.5	5.7	-	0.5	1.4	n.a.	11.3	2.6	6.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	46	82	163	344	646	917	1,236	5.7	4.6	3.3	3.8
Population (million)	14	18	23	31	37	40	42	2.1	1.2	0.6	0.9
CO_2 emissions (Mt)	28	54	115	223	318	362	394	5.6	2.6	1.1	1.7
GDP per capita ($2010 thousand)	3.3	4.5	7.0	11	18	23	30	3.5	3.4	2.7	2.9
Primary energy consump. per capita (toe)	0.9	1.2	2.1	2.9	3.4	3.7	3.9	3.3	1.2	0.7	0.9
Primary energy consumption per GDP[*2]	260	267	301	258	193	159	130	-0.1	-2.1	-1.9	-2.0
CO_2 emissions per GDP[*3]	608	658	708	647	493	394	319	-0.1	-1.9	-2.1	-2.1
CO_2 per primary energy consumption[*4]	2.3	2.5	2.4	2.5	2.6	2.5	2.4	0.1	0.1	-0.2	-0.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A30 | Myanmar [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total*1	9.4	11	13	19	29	38	47	100	100	100	2.3	3.0	2.3	2.6
Coal	0.2	0.1	0.3	0.4	3.6	6.5	10	0.6	2.0	22	6.9	17.5	5.4	10.2
Oil	1.3	0.7	2.0	4.4	8.5	12	15	6.8	23	32	7.2	4.9	2.8	3.7
Natural gas	0.3	0.8	1.2	3.5	5.2	7.6	10	7.1	18	22	6.1	2.7	3.5	3.2
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.1	0.2	0.8	3.2	4.2	5.1	1.0	4.3	11	8.4	9.9	2.4	5.4
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	-	0.1	0.1	0.2	-	-	0.5	n.a.	n.a.	6.8	n.a.
Biomass and waste	7.6	9.0	9.2	10	10	9.8	8.7	84	53	19	0.5	0.1	-0.8	-0.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	8.4	9.4	11	16	24	29	35	100	100	100	2.2	2.7	1.9	2.2
Industry	0.6	0.4	1.1	1.8	3.8	5.5	6.9	4.2	11	20	5.9	5.7	3.0	4.1
Transport	0.6	0.4	1.2	1.5	3.7	5.4	7.5	4.7	9.3	21	4.9	6.5	3.6	4.8
Buildings, etc.	7.0	8.5	9.1	13	15	17	19	90	77	55	1.6	1.4	1.1	1.2
Non-energy use	0.1	0.1	0.1	0.6	0.9	1.2	1.5	1.0	3.4	4.3	7.1	3.8	2.4	3.0
Coal	0.1	0.1	0.3	0.4	0.7	0.9	1.1	0.5	2.3	3.1	7.9	4.3	2.4	3.2
Oil	1.2	0.6	1.5	4.1	8.2	11	15	6.2	25	42	7.8	5.0	2.9	3.8
Natural gas	0.1	0.2	0.3	0.6	1.0	1.3	1.7	2.4	3.4	4.7	3.5	4.0	2.8	3.3
Electricity	0.1	0.1	0.3	1.3	3.9	6.2	9.1	1.6	8.0	26	8.7	8.0	4.4	5.8
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	6.0	n.a.
Renewables	6.9	8.4	9.0	10	10	9.7	8.6	89	61	25	0.7	0.1	-0.8	-0.5

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1.5	2.5	5.1	18	72	112	160	100	100	100	7.9	10.5	4.1	6.7
Coal	-	-	-	-	15	29	52	1.6	0.1	32	-5.2	68.4	6.5	28.6
Oil	0.5	0.3	0.7	0.1	0.2	0.2	0.2	11	0.3	0.1	-5.6	7.9	-0.5	2.8
Natural gas	0.2	1.0	2.5	8.1	20	32	47	39	45	29	8.5	6.6	4.4	5.3
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.8	1.2	1.9	9.7	37	49	59	48	55	37	8.4	9.9	2.4	5.4
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	-	0.3	0.8	1.8	-	-	1.1	n.a.	n.a.	10.1	n.a.
Wind	-	-	-	-	0.5	0.7	1.0	-	-	0.6	n.a.	n.a.	3.7	n.a.
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	5.9	6.7	13	62	150	246	375	9.0	6.5	4.7	5.4
Population (million)	33	41	46	53	59	61	62	1.0	0.8	0.3	0.5
CO_2 emissions (Mt)	5.1	4.0	9.4	21	49	75	106	6.6	6.3	3.9	4.9
GDP per capita ($2010 thousand)	0.2	0.2	0.3	1.2	2.5	4.0	6.0	7.9	5.6	4.4	4.9
Primary energy consump. per capita (toe)	0.3	0.3	0.3	0.4	0.5	0.6	0.7	1.3	2.2	2.1	2.1
Primary energy consumption per GDP*2	1,597	1,594	960	310	196	153	124	-6.1	-3.2	-2.2	-2.7
CO_2 emissions per GDP*3	868	597	705	336	328	305	283	-2.2	-0.2	-0.7	-0.5
CO_2 per primary energy consumption*4	0.5	0.4	0.7	1.1	1.7	2.0	2.3	4.2	3.2	1.5	2.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A31 | Philippines [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	22	29	40	55	97	127	161	100	100	100	2.5	4.2	2.5	3.2
Coal	0.5	1.5	5.2	14	25	33	40	5.3	26	25	9.0	4.1	2.4	3.1
Oil	10	11	16	19	36	51	69	38	34	43	2.1	4.9	3.3	4.0
Natural gas	-	-	-	3.3	7.6	12	16	-	6.0	10	n.a.	6.2	3.9	4.8
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	0.3	0.5	0.7	0.7	0.9	0.9	1.0	1.8	1.3	0.6	1.1	2.1	0.1	0.9
Geothermal	1.8	4.7	10	9.5	17	19	21	16	17	13	2.8	4.3	1.1	2.4
Solar, wind, etc.	-	-	-	0.2	0.6	1.2	2.0	-	0.3	1.2	n.a.	9.0	6.3	7.4
Biomass and waste	9.4	11	8.1	8.3	9.6	10	10	39	15	6.4	-1.1	1.1	0.4	0.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	16	20	24	32	59	81	108	100	100	100	1.8	4.5	3.1	3.7
Industry	3.4	4.7	5.3	7.6	14	18	23	24	24	21	1.9	4.2	2.7	3.3
Transport	3.3	4.5	8.1	11	26	38	53	23	36	50	3.6	5.9	3.7	4.6
Buildings, etc.	9.4	10	10	11	17	22	26	52	36	24	0.4	3.1	2.0	2.4
Non-energy use	0.3	0.2	0.3	1.1	2.2	3.5	5.6	1.2	3.6	5.2	6.3	4.9	4.8	4.8
Coal	0.2	0.6	0.8	2.8	4.7	5.9	7.0	3.1	9.0	6.5	6.1	3.7	2.0	2.7
Oil	6.8	8.1	13	17	34	49	67	41	52	62	2.8	5.3	3.4	4.2
Natural gas	-	-	-	0.1	0.1	0.2	0.2	-	0.2	0.2	n.a.	4.9	2.8	3.7
Electricity	1.5	1.8	3.1	6.4	13	19	26	9.3	20	24	4.9	5.3	3.5	4.2
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	6.0	n.a.
Renewables	7.8	9.1	6.9	5.8	7.0	7.3	7.5	46	18	7.0	-1.7	1.4	0.4	0.8

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	18	26	45	91	184	260	351	100	100	100	4.9	5.2	3.3	4.1
Coal	0.2	1.9	17	43	92	130	175	7.3	48	50	12.7	5.5	3.3	4.2
Oil	12	12	9.2	5.7	4.6	3.6	0.7	47	6.2	0.2	-3.0	-1.4	-9.3	-6.1
Natural gas	-	-	-	20	48	76	114	-	22	32	n.a.	6.5	4.4	5.3
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	3.5	6.1	7.8	8.1	11	11	11	23	8.9	3.2	1.1	2.1	0.1	0.9
Geothermal	2.1	5.5	12	11	20	23	25	21	12	7.1	2.8	4.3	1.1	2.4
Solar PV	-	-	-	1.1	3.6	8.7	15	-	1.2	4.3	n.a.	8.8	7.5	8.0
Wind	-	-	-	1.0	3.4	5.3	8.1	-	1.1	2.3	n.a.	9.2	4.5	6.4
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	0.4	-	0.7	1.3	1.8	2.2	1.6	0.8	0.6	2.0	4.4	2.6	3.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	80	95	125	284	620	915	1,305	4.3	5.7	3.8	4.6
Population (million)	47	62	78	103	125	139	151	2.0	1.4	0.9	1.1
CO_2 emissions (Mt)	31	36	67	115	218	297	386	4.5	4.7	2.9	3.6
GDP per capita ($2010 thousand)	1.7	1.5	1.6	2.8	4.9	6.6	8.6	2.3	4.3	2.8	3.4
Primary energy consump. per capita (toe)	0.5	0.5	0.5	0.5	0.8	0.9	1.1	0.5	2.8	1.6	2.1
Primary energy consumption per GDP[*2]	280	304	319	193	157	139	123	-1.7	-1.4	-1.2	-1.3
CO_2 emissions per GDP[*3]	393	383	533	404	352	324	296	0.2	-1.0	-0.9	-0.9
CO_2 per primary energy consumption[*4]	1.4	1.3	1.7	2.1	2.2	2.3	2.4	2.0	0.5	0.4	0.4

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A32 | Thailand [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total*1	22	42	72	139	182	215	246	100	100	100	4.7	2.0	1.5	1.7
Coal	0.5	3.8	7.7	15	20	23	25	9.1	11	10	5.5	2.0	1.0	1.4
Oil	11	18	32	55	67	78	88	43	40	36	4.4	1.4	1.4	1.4
Natural gas	-	5.0	17	37	49	54	58	12	27	24	8.0	2.0	0.9	1.4
Nuclear	-	-	-	-	-	3.7	8.8	-	-	3.6	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.4	0.5	0.6	0.6	0.7	0.7	1.0	0.4	0.3	1.3	0.5	0.1	0.3
Geothermal	-	-	-	-	-	-	-	-	-	-	0.0	11.1	1.1	5.1
Solar, wind, etc.	-	-	-	0.3	2.7	5.7	9.1	-	0.2	3.7	n.a.	16.3	6.3	10.4
Biomass and waste	11	15	15	28	39	46	51	35	20	21	2.5	2.3	1.3	1.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	15	29	51	98	125	147	168	100	100	100	4.8	1.8	1.5	1.6
Industry	4.0	8.7	17	31	41	50	57	30	32	34	5.1	2.0	1.6	1.8
Transport	3.2	9.0	15	25	29	31	33	31	26	20	4.0	1.0	0.7	0.8
Buildings, etc.	7.8	11	14	18	22	26	29	37	18	17	2.0	1.5	1.3	1.4
Non-energy use	0.2	0.4	5.6	23	32	40	49	1.5	23	29	16.5	2.5	2.1	2.3
Coal	0.1	1.3	3.5	6.1	6.2	6.5	6.9	4.5	6.2	4.1	6.1	0.2	0.5	0.4
Oil	7.3	15	29	54	65	75	85	52	55	51	5.1	1.4	1.3	1.4
Natural gas	-	0.1	1.1	7.2	12	15	19	0.5	7.4	11	16.4	3.7	2.3	2.8
Electricity	1.1	3.3	7.6	17	25	32	38	11	17	23	6.4	3.0	2.1	2.5
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	4.7	n.a.
Renewables	6.7	9.2	9.4	14	16	18	19	32	14	11	1.6	1.3	0.8	1.0

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	14	44	96	191	273	342	413	100	100	100	5.8	2.6	2.1	2.3
Coal	1.4	11	18	37	60	74	84	25	19	20	4.7	3.5	1.7	2.5
Oil	12	10	10	0.6	0.1	-	-	23	0.3	-	-10.6	-15.6	-100	-100
Natural gas	-	18	62	125	139	134	122	40	65	30	7.8	0.8	-0.6	-0.1
Nuclear	-	-	-	-	-	14	34	-	-	8.1	n.a.	n.a.	n.a.	n.a.
Hydro	1.3	5.0	6.0	7.0	7.5	7.6	7.7	11	3.6	1.9	1.3	0.5	0.1	0.3
Geothermal	-	-	-	-	-	-	-	-	-	-	0.0	11.1	1.1	5.1
Solar PV	-	-	-	3.4	30	63	102	-	1.8	25	n.a.	16.8	6.4	10.5
Wind	-	-	-	0.3	1.1	1.9	2.7	-	0.2	0.7	n.a.	8.8	4.5	6.3
CSP and marine	-	-	-	-	0.1	0.2	0.3	-	-	0.1	n.a.	n.a.	8.3	n.a.
Biomass and waste	-	-	0.5	18	36	48	60	-	9.6	15	n.a.	4.9	2.6	3.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	67	142	218	406	669	921	1,204	4.1	3.6	3.0	3.2
Population (million)	47	57	63	69	70	68	65	0.8	0.1	-0.3	-0.2
CO_2 emissions (Mt)	31	78	147	245	300	332	355	4.5	1.5	0.8	1.1
GDP per capita ($2010 thousand)	1.4	2.5	3.5	5.9	9.6	13	18	3.4	3.5	3.3	3.4
Primary energy consump. per capita (toe)	0.5	0.7	1.1	2.0	2.6	3.1	3.8	3.9	1.9	1.8	1.9
Primary energy consumption per GDP*2	331	296	332	341	272	233	204	0.5	-1.6	-1.4	-1.5
CO_2 emissions per GDP*3	468	548	675	603	449	361	295	0.4	-2.1	-2.1	-2.1
CO_2 per primary energy consumption*4	1.4	1.8	2.0	1.8	1.6	1.5	1.4	-0.2	-0.5	-0.7	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A33 | Viet Nam [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	14	18	29	81	150	207	266	100	100	100	6.0	4.5	2.9	3.6
Coal	2.3	2.2	4.4	28	62	90	118	12	34	44	10.2	5.9	3.3	4.4
Oil	1.8	2.7	7.8	22	39	54	73	15	28	28	8.5	4.0	3.2	3.5
Natural gas	-	-	1.1	9.5	24	34	42	-	12	16	36.9	6.9	2.8	4.5
Nuclear	-	-	-	-	-	4.2	8.6	-	-	3.2	n.a.	n.a.	n.a.	n.a.
Hydro	0.1	0.5	1.3	5.5	9.1	10	11	2.6	6.8	3.9	10.0	3.7	0.7	1.9
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	-	-	0.2	0.4	0.8	-	-	0.3	n.a.	20.3	6.1	11.7
Biomass and waste	10	12	14	16	16	14	12	70	19	4.5	0.9	-0.1	-1.3	-0.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	13	16	25	65	110	146	183	100	100	100	5.5	3.9	2.6	3.1
Industry	3.8	4.5	7.9	27	51	68	82	28	41	45	7.0	4.7	2.4	3.4
Transport	0.6	1.4	3.5	12	21	30	43	8.6	19	23	8.8	3.8	3.7	3.8
Buildings, etc.	8.6	10	14	23	33	40	48	63	35	26	3.1	2.7	1.9	2.2
Non-energy use	-	-	0.1	3.6	6.2	8.3	11	0.2	5.5	5.8	20.5	4.0	2.8	3.3
Coal	1.5	1.3	3.2	14	24	29	31	8.3	22	17	9.6	3.6	1.3	2.2
Oil	1.7	2.3	6.5	20	36	50	70	15	32	38	8.7	4.1	3.4	3.7
Natural gas	-	-	-	1.6	4.5	6.1	7.2	-	2.5	3.9	n.a.	7.6	2.4	4.5
Electricity	0.2	0.5	1.9	14	32	47	65	3.3	21	35	13.3	6.2	3.7	4.7
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	10.1	n.a.
Renewables	9.7	12	13	15	15	13	11	74	23	6.0	0.8	-0.1	-1.4	-0.9

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	3.6	8.7	27	165	398	601	825	100	100	100	12.0	6.5	3.7	4.9
Coal	1.4	2.0	3.1	54	168	285	429	23	33	52	13.5	8.5	4.8	6.3
Oil	0.7	1.3	4.5	1.1	2.5	3.3	3.6	15	0.7	0.4	-0.6	6.0	1.8	3.5
Natural gas	-	-	4.4	46	118	175	228	0.1	28	28	41.0	7.0	3.3	4.9
Nuclear	-	-	-	-	-	16	33	-	-	4.0	n.a.	n.a.	n.a.	n.a.
Hydro	1.5	5.4	15	64	106	117	122	62	39	15	10.0	3.7	0.7	1.9
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	-	1.4	2.7	4.7	-	-	0.6	n.a.	n.a.	6.4	n.a.
Wind	-	-	-	0.2	1.3	2.5	4.1	-	0.1	0.5	n.a.	14.3	5.8	9.2
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	-	-	0.1	0.2	0.2	0.3	-	-	-	n.a.	7.6	2.6	4.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	17	29	61	164	377	622	980	6.8	6.1	4.9	5.4
Population (million)	54	68	80	95	106	111	115	1.3	0.8	0.4	0.6
CO_2 emissions (Mt)	15	17	43	187	402	576	760	9.7	5.6	3.2	4.2
GDP per capita ($2010 thousand)	0.3	0.4	0.8	1.7	3.5	5.6	8.5	5.5	5.2	4.5	4.8
Primary energy consump. per capita (toe)	0.3	0.3	0.4	0.9	1.4	1.9	2.3	4.7	3.7	2.5	3.0
Primary energy consumption per GDP[*2]	851	607	470	494	399	333	272	-0.8	-1.5	-1.9	-1.7
CO_2 emissions per GDP[*3]	859	572	698	1,140	1,067	925	776	2.7	-0.5	-1.6	-1.1
CO_2 per primary energy consumption[*4]	1.0	0.9	1.5	2.3	2.7	2.8	2.9	3.5	1.0	0.3	0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A34 | North America [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	1,997	2,126	2,527	2,447	2,426	2,357	2,272	100	100	100	0.5	-0.1	-0.3	-0.2
Coal	397	484	566	359	275	207	144	23	15	6.3	-1.2	-1.9	-3.2	-2.6
Oil	885	833	958	886	806	736	666	39	36	29	0.2	-0.7	-0.9	-0.8
Natural gas	522	493	622	748	842	874	882	23	31	39	1.6	0.9	0.2	0.5
Nuclear	80	179	227	245	207	192	177	8.4	10	7.8	1.2	-1.2	-0.8	-1.0
Hydro	46	49	53	56	61	62	62	2.3	2.3	2.7	0.5	0.6	0.1	0.3
Geothermal	4.6	14	13	9.2	21	28	34	0.7	0.4	1.5	-1.6	6.2	2.3	3.9
Solar, wind, etc.	-	0.3	2.1	29	80	122	167	-	1.2	7.3	18.9	7.4	3.7	5.2
Biomass and waste	62	73	87	115	133	137	141	3.4	4.7	6.2	1.7	1.1	0.3	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,466	1,455	1,738	1,706	1,705	1,669	1,619	100	100	100	0.6	0.0	-0.3	-0.2
Industry	437	331	388	306	313	314	304	23	18	19	-0.3	0.2	-0.1	0.0
Transport	470	531	640	683	637	593	558	36	40	34	1.0	-0.5	-0.7	-0.6
Buildings, etc.	446	460	537	557	578	577	574	32	33	35	0.7	0.3	0.0	0.1
Non-energy use	114	134	173	160	178	184	182	9.2	9.4	11	0.7	0.7	0.1	0.4
Coal	60	59	36	20	18	17	15	4.0	1.2	0.9	-4.1	-0.7	-0.9	-0.8
Oil	769	752	874	837	767	704	643	52	49	40	0.4	-0.6	-0.9	-0.8
Natural gas	374	346	413	382	385	381	371	24	22	23	0.4	0.1	-0.2	-0.1
Electricity	200	262	342	368	435	470	496	18	22	31	1.3	1.2	0.7	0.9
Heat	1.0	2.8	6.1	7.2	6.3	5.8	5.2	0.2	0.4	0.3	3.7	-1.0	-0.9	-0.9
Hydrogen	-	-	-	-	0.2	0.2	0.2	-	-	-	n.a.	n.a.	1.5	n.a.
Renewables	62	33	66	93	94	91	89	2.3	5.4	5.5	4.1	0.1	-0.3	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	2,801	3,685	4,631	4,967	5,831	6,256	6,554	100	100	100	1.2	1.2	0.6	0.8
Coal	1,303	1,782	2,247	1,416	1,143	882	606	48	29	9.2	-0.9	-1.5	-3.1	-2.5
Oil	277	147	133	43	35	25	14	4.0	0.9	0.2	-4.6	-1.5	-4.4	-3.2
Natural gas	380	391	668	1,480	2,134	2,442	2,672	11	30	41	5.2	2.6	1.1	1.8
Nuclear	304	685	871	941	795	738	679	19	19	10	1.2	-1.2	-0.8	-1.0
Hydro	530	570	612	657	712	721	725	15	13	11	0.5	0.6	0.1	0.3
Geothermal	5.4	16	15	19	44	58	70	0.4	0.4	1.1	0.6	6.3	2.4	4.0
Solar PV	-	-	0.2	50	168	258	337	-	1.0	5.1	45.3	9.1	3.6	5.8
Wind	-	3.1	5.9	260	581	829	1,042	0.1	5.2	16	18.6	5.9	3.0	4.2
CSP and marine	-	0.7	0.6	3.7	52	100	174	-	0.1	2.7	6.7	20.7	6.3	12.0
Biomass and waste	1.8	90	80	92	162	196	228	2.5	1.9	3.5	0.1	4.1	1.7	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.7	5.7	5.7	5.7	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	7,310	10,078	14,056	18,748	25,056	30,555	36,229	2.4	2.1	1.9	2.0
Population (million)	252	277	313	359	396	418	436	1.0	0.7	0.5	0.6
CO_2 emissions (Mt)	5,033	5,226	6,203	5,409	5,008	4,585	4,153	0.1	-0.5	-0.9	-0.8
GDP per capita ($2010 thousand)	29	36	45	52	63	73	83	1.4	1.4	1.4	1.4
Primary energy consump. per capita (toe)	7.9	7.7	8.1	6.8	6.1	5.6	5.2	-0.5	-0.8	-0.8	-0.8
Primary energy consumption per GDP[*2]	273	211	180	131	97	77	63	-1.8	-2.1	-2.1	-2.1
CO_2 emissions per GDP[*3]	688	519	441	289	200	150	115	-2.2	-2.6	-2.7	-2.7
CO_2 per primary energy consumption[*4]	2.5	2.5	2.5	2.2	2.1	1.9	1.8	-0.4	-0.5	-0.6	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A35 | United States [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	1,805	1,915	2,274	2,167	2,135	2,074	1,999	100	100	100	0.5	-0.1	-0.3	-0.2
Coal	376	460	534	342	273	205	142	24	16	7.1	-1.1	-1.6	-3.2	-2.5
Oil	797	757	871	787	712	652	592	40	36	30	0.2	-0.7	-0.9	-0.8
Natural gas	477	438	548	653	718	742	747	23	30	37	1.5	0.7	0.2	0.4
Nuclear	69	159	208	219	186	179	169	8.3	10	8.5	1.2	-1.1	-0.5	-0.7
Hydro	24	23	22	23	25	26	26	1.2	1.1	1.3	0.0	0.7	0.1	0.3
Geothermal	4.6	14	13	9.2	21	28	34	0.7	0.4	1.7	-1.6	6.2	2.3	3.9
Solar, wind, etc.	-	0.3	2.1	26	74	114	156	-	1.2	7.8	18.5	7.6	3.8	5.4
Biomass and waste	54	62	73	102	120	124	128	3.3	4.7	6.4	1.9	1.2	0.3	0.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,311	1,294	1,546	1,515	1,508	1,476	1,432	100	100	100	0.6	0.0	-0.3	-0.2
Industry	387	284	332	264	271	273	265	22	17	18	-0.3	0.2	-0.1	0.0
Transport	425	488	588	622	577	538	507	38	41	35	0.9	-0.5	-0.6	-0.6
Buildings, etc.	397	403	473	493	508	509	506	31	33	35	0.8	0.2	0.0	0.1
Non-energy use	102	119	153	136	152	157	154	9.2	9.0	11	0.5	0.8	0.1	0.4
Coal	56	56	33	18	16	15	13	4.3	1.2	0.9	-4.4	-0.8	-0.9	-0.8
Oil	689	683	793	744	678	622	568	53	49	40	0.3	-0.7	-0.9	-0.8
Natural gas	338	303	360	336	338	335	325	23	22	23	0.4	0.0	-0.2	-0.1
Electricity	174	226	301	327	386	417	439	18	22	31	1.4	1.2	0.7	0.9
Heat	-	2.2	5.3	6.6	5.7	5.3	4.7	0.2	0.4	0.3	4.4	-1.1	-0.9	-1.0
Hydrogen	-	-	-	-	0.2	0.2	0.2	-	-	-	n.a.	n.a.	1.4	n.a.
Renewables	54	23	54	83	85	83	82	1.8	5.5	5.7	5.1	0.2	-0.2	0.0

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	2,427	3,203	4,026	4,300	5,060	5,439	5,703	100	100	100	1.1	1.2	0.6	0.8
Coal	1,243	1,700	2,129	1,354	1,143	882	606	53	31	11	-0.9	-1.2	-3.1	-2.3
Oil	263	131	118	35	26	17	8.3	4.1	0.8	0.1	-5.0	-2.0	-5.6	-4.1
Natural gas	370	382	634	1,418	1,956	2,223	2,426	12	33	43	5.2	2.3	1.1	1.6
Nuclear	266	612	798	840	715	685	650	19	20	11	1.2	-1.1	-0.5	-0.7
Hydro	279	273	253	270	295	298	300	8.5	6.3	5.3	0.0	0.7	0.1	0.3
Geothermal	5.4	16	15	19	44	58	70	0.5	0.4	1.2	0.6	6.3	2.4	4.0
Solar PV	-	-	0.2	47	161	248	325	-	1.1	5.7	44.9	9.2	3.6	5.9
Wind	-	3.1	5.7	229	518	747	936	0.1	5.3	16	18.1	6.0	3.0	4.2
CSP and marine	-	0.7	0.5	3.7	52	100	174	-	0.1	3.0	6.8	20.7	6.3	12.0
Biomass and waste	0.5	86	72	79	144	175	203	2.7	1.8	3.6	-0.3	4.4	1.7	2.8
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.6	5.6	5.6	5.6	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

								1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	2016	2030	2050	2050
GDP ($2010 billion)	6,529	9,064	12,713	16,920	22,637	27,647	32,825	2.4	2.1	1.9	2.0
Population (million)	227	250	282	323	356	375	391	1.0	0.7	0.5	0.6
CO_2 emissions (Mt)	4,620	4,817	5,700	4,870	4,482	4,075	3,668	0.0	-0.6	-1.0	-0.8
GDP per capita ($2010 thousand)	29	36	45	52	64	74	84	1.4	1.4	1.4	1.4
Primary energy consump. per capita (toe)	7.9	7.7	8.1	6.7	6.0	5.5	5.1	-0.5	-0.8	-0.8	-0.8
Primary energy consumption per GDP[*2]	276	211	179	128	94	75	61	-1.9	-2.2	-2.2	-2.2
CO_2 emissions per GDP[*3]	708	531	448	288	198	147	112	-2.3	-2.6	-2.8	-2.7
CO_2 per primary energy consumption[*4]	2.6	2.5	2.5	2.2	2.1	2.0	1.8	-0.4	-0.5	-0.7	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A36 | Latin America [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	382	464	600	840	1,068	1,230	1,325	100	100	100	2.3	1.7	1.1	1.3
Coal	13	21	27	45	55	68	74	4.6	5.4	5.6	2.9	1.5	1.4	1.5
Oil	223	238	303	361	427	456	452	51	43	34	1.6	1.2	0.3	0.7
Natural gas	48	72	119	208	278	359	426	16	25	32	4.2	2.1	2.1	2.1
Nuclear	0.6	3.2	5.3	9.0	17	18	15	0.7	1.1	1.2	4.0	4.7	-0.6	1.6
Hydro	19	33	50	63	77	82	88	7.2	7.5	6.7	2.5	1.5	0.7	1.0
Geothermal	1.2	5.1	6.4	6.6	21	30	37	1.1	0.8	2.8	1.0	8.8	2.8	5.2
Solar, wind, etc.	-	-	0.2	6.3	21	29	39	-	0.8	2.9	25.4	8.8	3.2	5.5
Biomass and waste	78	92	89	141	170	186	193	20	17	15	1.7	1.4	0.6	0.9

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	288	343	447	610	768	876	947	100	100	100	2.2	1.7	1.1	1.3
Industry	98	114	148	187	237	283	315	33	31	33	1.9	1.7	1.4	1.5
Transport	85	103	141	223	284	311	322	30	37	34	3.0	1.7	0.6	1.1
Buildings, etc.	88	100	120	162	201	230	251	29	27	27	1.9	1.6	1.1	1.3
Non-energy use	16	26	38	37	46	53	58	7.5	6.1	6.1	1.4	1.5	1.2	1.3
Coal	6.1	7.8	11	13	17	20	21	2.3	2.1	2.3	1.9	2.0	1.2	1.5
Oil	159	179	240	304	371	404	416	52	50	44	2.1	1.4	0.6	0.9
Natural gas	27	38	53	75	97	114	129	11	12	14	2.7	1.8	1.5	1.6
Electricity	27	44	69	113	162	207	248	13	19	26	3.6	2.6	2.2	2.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	0.1	0.2	0.2	-	-	-	n.a.	n.a.	3.4	n.a.
Renewables	68	74	74	104	121	130	133	22	17	14	1.3	1.0	0.5	0.7

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	380	623	1,009	1,628	2,299	2,893	3,386	100	100	100	3.8	2.5	2.0	2.2
Coal	7.8	23	43	107	139	191	220	3.8	6.6	6.5	6.0	1.8	2.3	2.1
Oil	111	128	198	178	153	131	63	21	11	1.9	1.3	-1.1	-4.4	-3.0
Natural gas	35	60	141	436	679	1,039	1,373	9.6	27	41	8.0	3.2	3.6	3.4
Nuclear	2.3	12	20	35	66	71	59	2.0	2.1	1.7	4.0	4.7	-0.6	1.6
Hydro	218	386	584	729	899	959	1,027	62	45	30	2.5	1.5	0.7	1.0
Geothermal	1.4	5.9	7.8	10	34	49	61	1.0	0.6	1.8	2.1	9.0	3.0	5.4
Solar PV	-	-	-	5.2	38	66	99	-	0.3	2.9	39.0	15.2	4.9	9.1
Wind	-	-	0.3	56	179	249	324	-	3.4	9.6	52.3	8.7	3.0	5.3
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	3.9	7.6	14	71	113	140	160	1.2	4.3	4.7	9.0	3.4	1.7	2.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.4	0.4	0.4	0.4	0.4	-	-	-	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	2,418	2,787	3,778	5,704	8,559	11,723	14,928	2.8	2.9	2.8	2.9
Population (million)	360	441	521	634	713	752	775	1.4	0.8	0.4	0.6
CO_2 emissions (Mt)	749	853	1,169	1,603	1,977	2,280	2,433	2.5	1.5	1.0	1.2
GDP per capita ($2010 thousand)	6.7	6.3	7.3	9.0	12	16	19	1.4	2.1	2.4	2.3
Primary energy consump. per capita (toe)	1.1	1.1	1.2	1.3	1.5	1.6	1.7	0.9	0.9	0.7	0.8
Primary energy consumption per GDP[*2]	158	167	159	147	125	105	89	-0.5	-1.2	-1.7	-1.5
CO_2 emissions per GDP[*3]	310	306	309	281	231	194	163	-0.3	-1.4	-1.7	-1.6
CO_2 per primary energy consumption[*4]	2.0	1.8	1.9	1.9	1.9	1.9	1.8	0.1	-0.2	0.0	-0.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A37 | OECD Europe [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	1,494	1,627	1,753	1,723	1,676	1,593	1,519	100	100	100	0.2	-0.2	-0.5	-0.4
Coal	464	448	331	269	219	177	146	28	16	9.6	-1.9	-1.5	-2.0	-1.8
Oil	688	611	653	560	499	446	402	38	33	26	-0.3	-0.8	-1.1	-1.0
Natural gas	206	262	394	414	452	453	437	16	24	29	1.8	0.6	-0.2	0.2
Nuclear	60	205	245	217	184	166	159	13	13	10	0.2	-1.2	-0.7	-0.9
Hydro	36	39	47	50	51	52	54	2.4	2.9	3.5	1.0	0.2	0.2	0.2
Geothermal	3.0	4.9	7.2	16	25	28	30	0.3	1.0	1.9	4.7	3.1	0.8	1.7
Solar, wind, etc.	0.1	0.3	2.7	41	78	103	126	-	2.4	8.3	20.4	4.7	2.4	3.3
Biomass and waste	36	55	72	155	166	166	165	3.4	9.0	11	4.0	0.5	0.0	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,081	1,133	1,231	1,230	1,217	1,166	1,119	100	100	100	0.3	-0.1	-0.4	-0.3
Industry	356	327	324	284	287	282	275	29	23	25	-0.5	0.1	-0.2	-0.1
Transport	209	267	317	343	305	274	250	24	28	22	1.0	-0.8	-1.0	-0.9
Buildings, etc.	425	438	475	499	515	498	482	39	41	43	0.5	0.2	-0.3	-0.1
Non-energy use	90	101	115	105	111	112	112	8.9	8.5	10	0.1	0.4	0.1	0.2
Coal	156	123	62	47	44	41	38	11	3.8	3.4	-3.7	-0.4	-0.7	-0.6
Oil	551	524	572	509	453	405	365	46	41	33	-0.1	-0.8	-1.1	-1.0
Natural gas	161	203	268	267	276	269	261	18	22	23	1.1	0.2	-0.3	-0.1
Electricity	147	192	233	266	300	315	324	17	22	29	1.3	0.9	0.4	0.6
Heat	35	43	41	47	45	41	37	3.8	3.9	3.3	0.4	-0.4	-0.9	-0.7
Hydrogen	-	-	-	-	0.1	0.1	0.1	-	-	-	n.a.	n.a.	2.6	n.a.
Renewables	31	47	55	94	98	95	93	4.2	7.7	8.3	2.7	0.3	-0.3	0.0

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	2,049	2,668	3,227	3,599	4,037	4,201	4,287	100	100	100	1.2	0.8	0.3	0.5
Coal	887	1,030	968	790	694	558	443	39	22	10	-1.0	-0.9	-2.2	-1.7
Oil	364	206	179	55	42	29	15	7.7	1.5	0.4	-5.0	-1.9	-4.9	-3.7
Natural gas	138	169	513	689	893	970	953	6.3	19	22	5.6	1.9	0.3	1.0
Nuclear	230	787	939	834	707	638	609	29	23	14	0.2	-1.2	-0.7	-0.9
Hydro	416	451	549	579	596	610	623	17	16	15	1.0	0.2	0.2	0.2
Geothermal	2.7	3.6	6.2	17	28	31	33	0.1	0.5	0.8	6.0	3.7	0.9	2.1
Solar PV	-	-	0.1	104	199	258	309	-	2.9	7.2	41.3	4.7	2.2	3.3
Wind	-	0.8	22	310	565	749	904	-	8.6	21	25.9	4.4	2.4	3.2
CSP and marine	0.5	0.5	0.5	6.1	34	47	65	-	0.2	1.5	10.1	13.0	3.3	7.2
Biomass and waste	11	21	48	210	274	306	327	0.8	5.8	7.6	9.3	1.9	0.9	1.3
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.3	1.4	5.7	5.7	5.7	5.7	-	0.2	0.1	11.8	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	9,927	12,691	15,934	20,165	25,706	29,301	32,707	1.8	1.7	1.2	1.4
Population (million)	475	502	524	569	587	591	590	0.5	0.2	0.0	0.1
CO_2 emissions (Mt)	4,110	3,908	3,902	3,466	3,162	2,837	2,544	-0.5	-0.7	-1.1	-0.9
GDP per capita ($2010 thousand)	21	25	30	35	44	50	55	1.3	1.5	1.2	1.3
Primary energy consump. per capita (toe)	3.1	3.2	3.3	3.0	2.9	2.7	2.6	-0.3	-0.4	-0.5	-0.5
Primary energy consumption per GDP[*2]	151	128	110	85	65	54	46	-1.5	-1.9	-1.7	-1.8
CO_2 emissions per GDP[*3]	414	308	245	172	123	97	78	-2.2	-2.4	-2.3	-2.3
CO_2 per primary energy consumption[*4]	2.8	2.4	2.2	2.0	1.9	1.8	1.7	-0.7	-0.5	-0.6	-0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A38 | Non-OECD Europe [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	1,241	1,530	1,000	1,130	1,252	1,321	1,403	100	100	100	-1.2	0.7	0.6	0.6
Coal	362	367	209	212	200	198	193	24	19	14	-2.1	-0.4	-0.2	-0.3
Oil	464	465	202	257	265	272	283	30	23	20	-2.3	0.2	0.3	0.3
Natural gas	355	600	488	529	609	665	713	39	47	51	-0.5	1.0	0.8	0.9
Nuclear	21	59	64	81	106	98	107	3.9	7.1	7.6	1.2	2.0	0.1	0.8
Hydro	20	23	23	27	28	29	30	1.5	2.4	2.1	0.7	0.3	0.3	0.3
Geothermal	-	-	0.1	0.2	0.5	0.6	0.6	-	-	-	9.0	6.2	0.7	2.9
Solar, wind, etc.	-	-	-	1.6	5.2	9.3	15	-	0.1	1.1	n.a.	8.9	5.4	6.8
Biomass and waste	21	17	16	24	39	49	63	1.1	2.2	4.5	1.4	3.4	2.3	2.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	869	1,067	651	713	780	824	876	100	100	100	-1.5	0.6	0.6	0.6
Industry	395	394	205	198	223	243	262	37	28	30	-2.6	0.8	0.8	0.8
Transport	107	171	110	145	149	148	148	16	20	17	-0.6	0.2	-0.1	0.1
Buildings, etc.	301	436	287	275	292	298	309	41	39	35	-1.8	0.4	0.3	0.3
Non-energy use	67	66	49	95	116	136	158	6.2	13	18	1.4	1.5	1.5	1.5
Coal	152	113	36	33	37	38	39	11	4.6	4.4	-4.7	0.8	0.3	0.5
Oil	310	278	145	205	216	221	229	26	29	26	-1.2	0.4	0.3	0.3
Natural gas	215	261	201	220	242	259	277	24	31	32	-0.6	0.7	0.7	0.7
Electricity	95	126	87	106	135	156	180	12	15	21	-0.6	1.7	1.5	1.6
Heat	78	277	171	132	132	133	135	26	19	15	-2.8	0.0	0.1	0.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	3.3	n.a.
Renewables	21	13	12	17	18	17	16	1.2	2.4	1.8	1.1	0.4	-0.6	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,461	1,888	1,428	1,764	2,147	2,390	2,625	100	100	100	-0.3	1.4	1.0	1.2
Coal	471	429	338	395	438	474	469	23	22	18	-0.3	0.7	0.3	0.5
Oil	357	256	70	25	24	24	21	14	1.4	0.8	-8.6	-0.2	-0.8	-0.5
Natural gas	295	714	503	699	854	1,003	1,106	38	40	42	-0.1	1.4	1.3	1.4
Nuclear	79	226	242	307	408	378	412	12	17	16	1.2	2.0	0.1	0.9
Hydro	232	262	272	315	329	340	347	14	18	13	0.7	0.3	0.3	0.3
Geothermal	-	-	0.1	0.4	1.7	2.0	2.2	-	-	0.1	11.2	10.2	1.1	4.8
Solar PV	-	-	-	4.8	18	32	48	-	0.3	1.8	n.a.	9.7	5.2	7.0
Wind	-	-	-	12	40	75	121	-	0.7	4.6	n.a.	9.1	5.7	7.0
CSP and marine	-	-	-	-	-	0.1	0.2	-	-	-	n.a.	n.a.	12.7	n.a.
Biomass and waste	27	-	2.6	5.0	35	63	99	-	0.3	3.8	19.5	14.9	5.4	9.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.1	0.4	0.4	0.4	0.4	-	-	-	9.3	0.0	0.0	0.0

Energy and economic indicators

								1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	2016	2030	2050	2050
GDP ($2010 billion)	1,779	2,143	1,497	2,727	3,815	4,817	6,023	0.9	2.4	2.3	2.4
Population (million)	321	341	339	342	345	341	338	0.0	0.1	-0.1	0.0
CO_2 emissions (Mt)	3,319	3,840	2,296	2,425	2,525	2,618	2,683	-1.8	0.3	0.3	0.3
GDP per capita ($2010 thousand)	5.5	6.3	4.4	8.0	11	14	18	0.9	2.4	2.4	2.4
Primary energy consump. per capita (toe)	3.9	4.5	3.0	3.3	3.6	3.9	4.2	-1.2	0.7	0.7	0.7
Primary energy consumption per GDP[*2]	698	714	668	414	328	274	233	-2.1	-1.7	-1.7	-1.7
CO_2 emissions per GDP[*3]	1,865	1,792	1,533	889	662	543	446	-2.7	-2.1	-2.0	-2.0
CO_2 per primary energy consumption[*4]	2.7	2.5	2.3	2.1	2.0	2.0	1.9	-0.6	-0.4	-0.3	-0.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A39 | European Union [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	n.a.	1,646	1,695	1,599	1,553	1,475	1,407	100	100	100	-0.1	-0.2	-0.5	-0.4
Coal	n.a.	454	321	241	196	159	131	28	15	9.3	-2.4	-1.5	-2.0	-1.8
Oil	n.a.	608	625	522	464	414	371	37	33	26	-0.6	-0.8	-1.1	-1.0
Natural gas	n.a.	297	396	383	420	422	406	18	24	29	1.0	0.7	-0.2	0.2
Nuclear	n.a.	207	246	219	186	167	161	13	14	11	0.2	-1.2	-0.7	-0.9
Hydro	n.a.	25	31	30	31	32	32	1.5	1.9	2.3	0.7	0.2	0.2	0.2
Geothermal	n.a.	3.2	4.6	6.7	8.6	9.4	10	0.2	0.4	0.7	2.9	1.9	0.8	1.2
Solar, wind, etc.	n.a.	0.3	2.4	40	76	101	124	-	2.5	8.8	20.6	4.8	2.5	3.4
Biomass and waste	n.a.	48	67	155	168	168	169	2.9	9.7	12	4.7	0.5	0.0	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	n.a.	1,134	1,179	1,138	1,127	1,078	1,032	100	100	100	0.0	-0.1	-0.4	-0.3
Industry	n.a.	345	308	257	262	257	250	30	23	24	-1.1	0.1	-0.2	-0.1
Transport	n.a.	259	303	319	284	254	231	23	28	22	0.8	-0.8	-1.0	-1.0
Buildings, etc.	n.a.	430	454	463	480	463	448	38	41	43	0.3	0.2	-0.3	-0.1
Non-energy use	n.a.	100	113	98	102	103	103	8.8	8.6	10	-0.1	0.3	0.1	0.2
Coal	n.a.	120	51	34	33	31	28	11	3.0	2.8	-4.7	-0.3	-0.7	-0.6
Oil	n.a.	506	543	471	420	374	335	45	41	32	-0.3	-0.8	-1.1	-1.0
Natural gas	n.a.	227	272	252	262	254	247	20	22	24	0.4	0.3	-0.3	-0.1
Electricity	n.a.	186	217	239	271	285	294	16	21	29	1.0	0.9	0.4	0.6
Heat	n.a.	55	45	48	46	43	39	4.9	4.2	3.8	-0.5	-0.2	-0.8	-0.6
Hydrogen	n.a.	-	-	-	0.1	0.1	0.1	-	-	-	n.a.	n.a.	2.6	n.a.
Renewables	n.a.	40	50	93	96	92	88	3.5	8.2	8.6	3.3	0.2	-0.4	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	n.a.	2,577	3,006	3,228	3,654	3,839	3,950	100	100	100	0.9	0.9	0.4	0.6
Coal	n.a.	1,050	968	736	649	527	422	41	23	11	-1.4	-0.9	-2.1	-1.6
Oil	n.a.	224	181	60	46	32	18	8.7	1.8	0.5	-5.0	-1.8	-4.6	-3.5
Natural gas	n.a.	193	480	611	792	868	849	7.5	19	21	4.5	1.9	0.3	1.0
Nuclear	n.a.	795	945	840	713	643	616	31	26	16	0.2	-1.2	-0.7	-0.9
Hydro	n.a.	290	357	350	360	367	374	11	11	9.5	0.7	0.2	0.2	0.2
Geothermal	n.a.	3.2	4.8	6.6	8.7	9.6	10	0.1	0.2	0.3	2.8	1.9	0.9	1.3
Solar PV	n.a.	-	0.1	105	205	269	326	-	3.3	8.2	41.8	4.9	2.3	3.4
Wind	n.a.	0.8	22	303	564	752	910	-	9.4	23	25.8	4.5	2.4	3.3
CSP and marine	n.a.	0.5	0.5	6.1	35	52	78	-	0.2	2.0	10.1	13.2	4.1	7.8
Biomass and waste	n.a.	20	46	206	276	315	344	0.8	6.4	8.7	9.5	2.1	1.1	1.5
Hydrogen	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	n.a.	0.2	1.4	5.0	4.3	4.3	4.3	-	0.2	0.1	12.9	-1.0	0.0	-0.4

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	n.a.	11,895	14,789	18,309	23,323	26,643	29,798	1.7	1.7	1.2	1.4
Population (million)	n.a.	478	488	511	524	526	523	0.3	0.2	0.0	0.1
CO_2 emissions (Mt)	n.a.	4,018	3,798	3,195	2,859	2,560	2,286	-0.9	-0.8	-1.1	-1.0
GDP per capita ($2010 thousand)	n.a.	25	30	36	45	51	57	1.4	1.6	1.2	1.4
Primary energy consump. per capita (toe)	n.a.	3.4	3.5	3.1	3.0	2.8	2.7	-0.4	-0.4	-0.5	-0.4
Primary energy consumption per GDP[*2]	n.a.	138	115	87	67	55	47	-1.8	-1.9	-1.7	-1.8
CO_2 emissions per GDP[*3]	n.a.	338	257	175	123	96	77	-2.5	-2.5	-2.3	-2.4
CO_2 per primary energy consumption[*4]	n.a.	2.4	2.2	2.0	1.8	1.7	1.6	-0.8	-0.6	-0.6	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A40 | Africa [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	276	392	498	818	1,116	1,390	1,644	100	100	100	2.9	2.2	2.0	2.1
Coal	52	74	90	108	128	149	166	19	13	10	1.5	1.2	1.3	1.3
Oil	64	85	100	184	275	373	459	22	23	28	3.0	2.9	2.6	2.7
Natural gas	12	30	47	115	194	283	395	7.5	14	24	5.4	3.8	3.6	3.7
Nuclear	-	2.2	3.4	3.9	5.8	10	8.8	0.6	0.5	0.5	2.2	2.9	2.1	2.4
Hydro	4.1	4.8	6.4	10.0	19	29	40	1.2	1.2	2.4	2.8	4.7	3.8	4.2
Geothermal	-	0.3	0.4	3.6	13	21	29	0.1	0.4	1.8	10.3	9.8	4.0	6.4
Solar, wind, etc.	-	-	-	1.5	11	23	39	-	0.2	2.3	35.9	15.8	6.3	10.1
Biomass and waste	143	196	249	390	468	502	507	50	48	31	2.7	1.3	0.4	0.8

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	218	292	368	594	816	1,012	1,193	100	100	100	2.8	2.3	1.9	2.1
Industry	46	55	58	87	132	183	229	19	15	19	1.8	3.0	2.8	2.9
Transport	27	38	54	117	165	219	279	13	20	23	4.5	2.5	2.6	2.6
Buildings, etc.	139	188	241	370	488	569	631	64	62	53	2.6	2.0	1.3	1.6
Non-energy use	5.4	11	15	20	29	41	54	3.8	3.3	4.6	2.2	3.0	3.1	3.1
Coal	22	20	19	19	22	25	27	6.7	3.1	2.3	-0.2	1.1	1.0	1.1
Oil	54	71	89	165	246	329	407	24	28	34	3.3	2.9	2.6	2.7
Natural gas	2.8	8.6	14	36	58	79	99	2.9	6.0	8.3	5.6	3.6	2.7	3.1
Electricity	14	22	31	55	96	153	229	7.6	9.2	19	3.5	4.1	4.5	4.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	0.1	0.1	-	-	-	n.a.	n.a.	5.6	n.a.
Renewables	126	171	215	320	394	426	431	59	54	36	2.4	1.5	0.4	0.9

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	184	316	442	801	1,372	2,139	3,141	100	100	100	3.6	3.9	4.2	4.1
Coal	100	165	209	254	334	418	503	52	32	16	1.7	2.0	2.1	2.0
Oil	22	41	51	86	130	187	217	13	11	6.9	2.9	3.0	2.6	2.8
Natural gas	14	45	92	308	550	938	1,559	14	38	50	7.7	4.2	5.3	4.9
Nuclear	-	8.4	13	15	22	39	34	2.7	1.9	1.1	2.2	2.9	2.1	2.4
Hydro	47	56	75	116	220	336	465	18	15	15	2.8	4.7	3.8	4.2
Geothermal	-	0.3	0.4	4.2	16	24	34	0.1	0.5	1.1	10.3	9.8	4.0	6.4
Solar PV	-	-	-	3.3	33	76	142	-	0.4	4.5	n.a.	17.8	7.6	11.7
Wind	-	-	0.2	10	37	61	102	-	1.3	3.2	n.a.	9.6	5.2	7.0
CSP and marine	-	-	-	0.9	20	42	66	-	0.1	2.1	n.a.	24.7	6.2	13.5
Biomass and waste	0.2	0.5	1.1	1.9	9.5	14	18	0.1	0.2	0.6	5.7	12.0	3.2	6.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.1	1.6	1.6	1.6	1.6	-	0.2	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	717	876	1,146	2,307	4,168	6,725	9,996	3.8	4.3	4.5	4.4
Population (million)	479	634	816	1,223	1,701	2,097	2,524	2.6	2.4	2.0	2.2
CO_2 emissions (Mt)	396	538	661	1,155	1,644	2,191	2,743	3.0	2.6	2.6	2.6
GDP per capita ($2010 thousand)	1.5	1.4	1.4	1.9	2.5	3.2	4.0	1.2	1.9	2.4	2.2
Primary energy consump. per capita (toe)	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.3	-0.1	0.0	-0.1
Primary energy consumption per GDP[*2]	384	447	434	354	268	207	164	-0.9	-2.0	-2.4	-2.2
CO_2 emissions per GDP[*3]	552	614	576	501	394	326	274	-0.8	-1.7	-1.8	-1.8
CO_2 per primary energy consumption[*4]	1.4	1.4	1.3	1.4	1.5	1.6	1.7	0.1	0.3	0.6	0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A41 | Middle East [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total*1	121	223	372	757	1,019	1,184	1,313	100	100	100	4.8	2.1	1.3	1.6
Coal	1.2	3.0	8.1	8.7	13	14	14	1.3	1.2	1.1	4.2	2.9	0.4	1.4
Oil	90	146	217	327	421	481	526	66	43	40	3.1	1.8	1.1	1.4
Natural gas	29	72	145	415	553	640	708	32	55	54	7.0	2.1	1.2	1.6
Nuclear	-	-	-	1.7	22	33	39	-	0.2	3.0	n.a.	19.8	3.0	9.6
Hydro	0.8	1.0	0.7	1.8	2.1	2.3	2.5	0.5	0.2	0.2	2.2	1.0	1.0	1.0
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	0.4	0.7	0.9	6.7	12	21	0.2	0.1	1.6	3.2	15.0	5.9	9.6
Biomass and waste	0.3	0.4	0.4	0.9	1.1	1.0	1.0	0.2	0.1	0.1	2.9	0.8	-0.3	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	84	157	253	498	672	782	870	100	100	100	4.5	2.2	1.3	1.7
Industry	30	47	71	152	204	241	270	30	30	31	4.6	2.1	1.4	1.7
Transport	26	51	75	139	174	193	207	32	28	24	3.9	1.6	0.9	1.2
Buildings, etc.	22	40	75	136	181	207	226	25	27	26	4.8	2.1	1.1	1.5
Non-energy use	5.6	20	32	72	112	141	167	12	14	19	5.1	3.2	2.0	2.5
Coal	0.3	0.2	0.5	2.9	3.7	4.0	4.2	0.1	0.6	0.5	11.2	1.6	0.7	1.0
Oil	67	108	153	236	307	351	383	69	47	44	3.1	1.9	1.1	1.4
Natural gas	9.8	31	65	178	242	277	301	20	36	35	6.9	2.2	1.1	1.6
Electricity	6.5	17	33	80	118	148	180	11	16	21	6.1	2.9	2.1	2.4
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	0.1	0.1	-	-	-	n.a.	n.a.	4.1	n.a.
Renewables	0.2	0.7	1.0	1.4	1.6	1.7	1.7	0.5	0.3	0.2	2.5	1.0	0.3	0.6

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	95	244	472	1,147	1,694	2,096	2,510	100	100	100	6.1	2.8	2.0	2.3
Coal	0.1	11	30	25	40	44	45	4.3	2.2	1.8	3.3	3.5	0.6	1.8
Oil	47	108	188	306	383	409	419	44	27	17	4.1	1.6	0.4	0.9
Natural gas	39	114	246	785	1,106	1,384	1,673	47	68	67	7.7	2.5	2.1	2.3
Nuclear	-	-	-	6.6	83	127	151	-	0.6	6.0	n.a.	19.8	3.0	9.6
Hydro	9.7	12	8.0	21	24	27	30	4.9	1.8	1.2	2.2	1.0	1.0	1.0
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	2.9	44	78	138	-	0.3	5.5	n.a.	21.5	5.9	12.1
Wind	-	-	-	0.6	7.1	16	33	-	0.1	1.3	28.2	18.7	8.0	12.3
CSP and marine	-	-	-	0.3	6.0	10	20	-	-	0.8	n.a.	25.1	6.2	13.6
Biomass and waste	-	-	-	0.1	0.3	0.4	0.6	-	-	-	n.a.	6.2	2.9	4.3
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	972	1,024	1,525	2,749	4,118	5,467	7,075	3.9	2.9	2.7	2.8
Population (million)	92	132	168	242	299	335	367	2.3	1.5	1.0	1.2
CO_2 emissions (Mt)	313	571	948	1,837	2,341	2,649	2,870	4.6	1.7	1.0	1.3
GDP per capita ($2010 thousand)	11	7.7	9.1	11	14	16	19	1.5	1.4	1.7	1.6
Primary energy consump. per capita (toe)	1.3	1.7	2.2	3.1	3.4	3.5	3.6	2.4	0.6	0.2	0.4
Primary energy consumption per GDP*2	125	217	244	275	247	217	186	0.9	-0.8	-1.4	-1.2
CO_2 emissions per GDP*3	322	557	622	668	568	485	406	0.7	-1.2	-1.7	-1.5
CO_2 per primary energy consumption*4	2.6	2.6	2.6	2.4	2.3	2.2	2.2	-0.2	-0.4	-0.3	-0.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A42 | Oceania [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	79	99	125	151	154	151	145	100	100	100	1.6	0.2	-0.3	-0.1
Coal	28	36	49	45	38	33	28	36	30	20	0.8	-1.2	-1.4	-1.3
Oil	34	35	40	50	49	46	42	35	33	29	1.4	-0.2	-0.7	-0.5
Natural gas	8.3	19	24	39	43	44	43	19	26	30	2.9	0.7	0.0	0.3
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	2.7	3.2	3.5	3.5	3.5	3.6	3.6	3.2	2.3	2.5	0.3	0.1	0.1	0.1
Geothermal	1.0	1.5	1.9	4.8	7.6	8.0	8.4	1.5	3.2	5.8	4.7	3.3	0.5	1.6
Solar, wind, etc.	-	0.1	0.1	2.2	6.1	8.8	12	0.1	1.5	8.4	11.6	7.6	3.5	5.2
Biomass and waste	4.1	4.7	6.2	6.6	7.3	7.5	7.5	4.8	4.4	5.2	1.3	0.7	0.1	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050				
Total	54	66	83	96	101	102	100	100	100	100	1.4	0.4	-0.1	0.1
Industry	20	23	28	27	30	30	29	35	29	29	0.7	0.6	-0.2	0.1
Transport	19	24	30	38	38	37	36	36	39	35	1.8	0.0	-0.3	-0.2
Buildings, etc.	11	15	19	24	27	29	30	22	25	29	1.9	0.8	0.4	0.6
Non-energy use	3.1	4.6	6.1	6.2	6.4	6.4	6.4	6.9	6.5	6.4	1.2	0.3	0.0	0.1
Coal	5.3	5.2	4.7	3.0	3.1	3.0	2.8	7.9	3.1	2.8	-2.1	0.3	-0.6	-0.2
Oil	31	33	40	49	48	46	43	50	51	43	1.5	-0.1	-0.6	-0.4
Natural gas	5.4	10	14	16	17	17	17	16	17	17	1.7	0.5	0.0	0.2
Electricity	8.5	14	18	22	26	29	31	20	22	31	1.8	1.4	0.9	1.1
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	3.3	n.a.
Renewables	4.0	4.1	5.6	6.1	6.4	6.2	5.8	6.2	6.3	5.8	1.5	0.4	-0.5	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050				
Total	118	187	249	299	361	395	420	100	100	100	1.8	1.4	0.8	1.0
Coal	70	122	176	164	158	150	132	65	55	32	1.1	-0.3	-0.9	-0.6
Oil	5.2	3.6	1.8	5.6	4.9	4.3	3.5	1.9	1.9	0.8	1.7	-0.9	-1.7	-1.4
Natural gas	8.7	20	26	56	73	81	82	11	19	20	4.0	1.8	0.6	1.1
Nuclear	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydro	32	37	41	41	41	41	42	20	14	9.9	0.3	0.1	0.1	0.1
Geothermal	1.2	2.1	2.9	7.4	12	13	13	1.1	2.5	3.1	4.9	3.4	0.5	1.7
Solar PV	-	-	-	6.3	22	32	47	-	2.1	11	n.a.	9.4	3.8	6.1
Wind	-	-	0.2	15	43	64	87	-	4.8	21	n.a.	8.1	3.6	5.4
CSP and marine	-	-	-	-	-	0.1	0.2	-	-	-	n.a.	19.2	6.5	11.5
Biomass and waste	0.7	1.3	1.7	4.3	7.4	10	13	0.7	1.4	3.1	4.9	3.9	2.8	3.3
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	0.1	0.1	0.1	0.1	0.1	0.1	-	-	-	-0.5	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	526	721	996	1,570	2,193	2,621	3,050	3.0	2.4	1.7	2.0
Population (million)	18	20	23	29	34	36	39	1.4	1.1	0.8	0.9
CO_2 emissions (Mt)	230	282	363	423	402	376	343	1.6	-0.4	-0.8	-0.6
GDP per capita ($2010 thousand)	30	35	43	54	65	72	78	1.7	1.3	0.9	1.1
Primary energy consump. per capita (toe)	4.4	4.9	5.4	5.2	4.6	4.1	3.7	0.3	-0.9	-1.1	-1.0
Primary energy consumption per GDP[*2]	150	137	126	96	70	58	48	-1.4	-2.2	-1.9	-2.0
CO_2 emissions per GDP[*3]	437	391	365	269	183	143	112	-1.4	-2.7	-2.4	-2.5
CO_2 per primary energy consumption[*4]	2.9	2.8	2.9	2.8	2.6	2.5	2.4	-0.1	-0.5	-0.5	-0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A43 | OECD [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	4,060	4,522	5,287	5,252	5,258	5,108	4,918	100	100	100	0.6	0.0	-0.3	-0.2
Coal	966	1,076	1,094	887	747	631	517	24	17	11	-0.7	-1.2	-1.8	-1.6
Oil	1,938	1,867	2,105	1,887	1,727	1,581	1,437	41	36	29	0.0	-0.6	-0.9	-0.8
Natural gas	778	845	1,164	1,414	1,578	1,632	1,632	19	27	33	2.0	0.8	0.2	0.4
Nuclear	162	451	586	512	474	429	397	10.0	9.8	8.1	0.5	-0.6	-0.9	-0.7
Hydro	94	102	115	121	130	132	134	2.3	2.3	2.7	0.7	0.5	0.2	0.3
Geothermal	10	27	30	36	71	89	105	0.6	0.7	2.1	1.2	4.9	2.0	3.2
Solar, wind, etc.	0.1	2.0	5.9	80	179	255	332	-	1.5	6.8	15.3	5.9	3.1	4.3
Biomass and waste	111	150	185	313	351	358	363	3.3	6.0	7.4	2.9	0.8	0.2	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	2,937	3,102	3,625	3,654	3,674	3,589	3,479	100	100	100	0.6	0.0	-0.3	-0.1
Industry	940	835	910	792	818	825	810	27	22	23	-0.2	0.2	-0.1	0.1
Transport	781	936	1,140	1,232	1,146	1,063	994	30	34	29	1.1	-0.5	-0.7	-0.6
Buildings, etc.	972	1,038	1,205	1,265	1,317	1,300	1,277	33	35	37	0.8	0.3	-0.2	0.0
Non-energy use	243	292	370	365	393	401	398	9.4	10.0	11	0.9	0.5	0.1	0.3
Coal	259	228	134	103	96	89	82	7.4	2.8	2.4	-3.0	-0.5	-0.8	-0.7
Oil	1,570	1,586	1,838	1,729	1,594	1,466	1,343	51	47	39	0.3	-0.6	-0.9	-0.7
Natural gas	559	590	745	735	761	752	733	19	20	21	0.8	0.2	-0.2	0.0
Electricity	408	551	713	813	947	1,016	1,066	18	22	31	1.5	1.1	0.6	0.8
Heat	36	46	51	60	56	52	48	1.5	1.6	1.4	1.0	-0.5	-0.8	-0.7
Hydrogen	-	-	-	-	0.3	0.5	0.5	-	-	-	n.a.	n.a.	1.9	n.a.
Renewables	105	100	144	215	221	214	208	3.2	5.9	6.0	3.0	0.2	-0.3	-0.1

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	5,656	7,640	9,700	10,876	12,608	13,453	14,006	100	100	100	1.4	1.1	0.5	0.7
Coal	2,319	3,089	3,760	3,020	2,668	2,299	1,881	40	28	13	-0.1	-0.9	-1.7	-1.4
Oil	980	688	584	243	180	131	72	9.0	2.2	0.5	-3.9	-2.1	-4.5	-3.5
Natural gas	618	773	1,538	2,963	3,948	4,492	4,822	10	27	34	5.3	2.1	1.0	1.4
Nuclear	621	1,729	2,249	1,965	1,818	1,648	1,524	23	18	11	0.5	-0.6	-0.9	-0.7
Hydro	1,093	1,185	1,341	1,412	1,508	1,535	1,555	16	13	11	0.7	0.5	0.2	0.3
Geothermal	11	29	33	51	111	145	173	0.4	0.5	1.2	2.3	5.7	2.2	3.6
Solar PV	-	0.1	0.7	219	496	705	901	-	2.0	6.4	35.3	6.0	3.0	4.2
Wind	-	3.8	29	605	1,240	1,714	2,133	0.1	5.6	15	21.5	5.3	2.7	3.8
CSP and marine	0.5	1.2	1.1	10	88	152	247	-	0.1	1.8	8.6	16.6	5.3	9.8
Biomass and waste	13	122	143	353	517	599	665	1.6	3.2	4.7	4.2	2.8	1.3	1.9
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	34	34	34	34	0.3	0.3	0.2	2.1	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	21,458	29,234	38,070	49,348	63,980	75,356	86,697	2.0	1.9	1.5	1.7
Population (million)	980	1,064	1,150	1,281	1,358	1,391	1,409	0.7	0.4	0.2	0.3
CO_2 emissions (Mt)	10,616	10,962	12,421	11,549	10,815	10,023	9,157	0.2	-0.5	-0.8	-0.7
GDP per capita ($2010 thousand)	22	27	33	39	47	54	62	1.3	1.5	1.3	1.4
Primary energy consump. per capita (toe)	4.1	4.2	4.6	4.1	3.9	3.7	3.5	-0.1	-0.4	-0.5	-0.5
Primary energy consumption per GDP[*2]	189	155	139	106	82	68	57	-1.4	-1.8	-1.8	-1.8
CO_2 emissions per GDP[*3]	495	375	326	234	169	133	106	-1.8	-2.3	-2.3	-2.3
CO_2 per primary energy consumption[*4]	2.6	2.4	2.3	2.2	2.1	2.0	1.9	-0.4	-0.5	-0.5	-0.5

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A44 | Non-OECD [Reference Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	2,969	4,050	4,475	8,111	10,779	12,454	13,692	100	100	100	2.7	2.1	1.2	1.6
Coal	817	1,144	1,222	2,843	3,420	3,721	3,806	28	35	28	3.6	1.3	0.5	0.9
Oil	988	1,165	1,284	2,105	2,833	3,281	3,600	29	26	26	2.3	2.1	1.2	1.6
Natural gas	454	818	908	1,621	2,382	2,960	3,497	20	20	26	2.7	2.8	1.9	2.3
Nuclear	24	74	89	167	340	427	514	1.8	2.1	3.8	3.2	5.2	2.1	3.4
Hydro	54	82	110	228	295	334	367	2.0	2.8	2.7	4.0	1.9	1.1	1.4
Geothermal	2.2	7.6	22	45	112	145	178	0.2	0.5	1.3	7.0	6.8	2.4	4.2
Solar, wind, etc.	-	0.5	2.1	65	209	317	429	-	0.8	3.1	20.8	8.8	3.7	5.7
Biomass and waste	631	759	837	1,036	1,187	1,269	1,300	19	13	9.5	1.2	1.0	0.5	0.7

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	2,252	2,967	3,136	5,503	7,168	8,254	9,133	100	100	100	2.4	1.9	1.2	1.5
Industry	825	968	957	1,960	2,396	2,710	2,961	33	36	32	2.7	1.4	1.1	1.2
Transport	286	432	544	1,117	1,577	1,832	2,032	15	20	22	3.7	2.5	1.3	1.8
Buildings, etc.	1,030	1,379	1,392	1,920	2,490	2,857	3,160	46	35	35	1.3	1.9	1.2	1.5
Non-energy use	111	187	243	505	705	855	981	6.3	9.2	11	3.9	2.4	1.7	2.0
Coal	444	524	408	933	954	960	938	18	17	10	2.2	0.2	-0.1	0.0
Oil	697	817	1,010	1,781	2,449	2,854	3,160	28	32	35	3.0	2.3	1.3	1.7
Natural gas	256	354	372	706	1,020	1,219	1,376	12	13	15	2.7	2.7	1.5	2.0
Electricity	177	283	377	981	1,542	1,974	2,415	9.5	18	26	4.9	3.3	2.3	2.7
Heat	85	291	197	223	237	245	251	9.8	4.1	2.7	-1.0	0.4	0.3	0.3
Hydrogen	-	-	-	-	0.4	0.7	0.8	-	-	-	n.a.	n.a.	4.0	n.a.
Renewables	593	698	772	880	964	1,001	992	24	16	11	0.9	0.7	0.1	0.4

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	2,628	4,212	5,741	14,097	21,861	27,459	32,909	100	100	100	4.8	3.2	2.1	2.5
Coal	817	1,342	2,242	6,575	9,206	10,796	12,031	32	47	37	6.3	2.4	1.3	1.8
Oil	678	635	628	689	802	861	821	15	4.9	2.5	0.3	1.1	0.1	0.5
Natural gas	381	977	1,209	2,831	4,638	6,521	8,716	23	20	26	4.2	3.6	3.2	3.4
Nuclear	93	283	341	641	1,305	1,639	1,972	6.7	4.5	6.0	3.2	5.2	2.1	3.4
Hydro	624	959	1,277	2,649	3,432	3,881	4,269	23	19	13	4.0	1.9	1.1	1.4
Geothermal	2.6	7.8	19	30	84	109	135	0.2	0.2	0.4	5.4	7.5	2.4	4.5
Solar PV	-	-	0.3	109	733	1,218	1,752	-	0.8	5.3	52.1	14.6	4.5	8.5
Wind	-	-	2.8	352	1,205	1,786	2,373	-	2.5	7.2	42.5	9.2	3.4	5.8
CSP and marine	-	-	-	1.2	30	63	104	-	-	0.3	21.9	25.9	6.4	14.0
Biomass and waste	31	7.7	21	217	425	583	734	0.2	1.5	2.2	13.7	4.9	2.8	3.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	0.6	2.3	2.3	2.3	2.3	-	-	-	17.2	0.0	0.0	0.0

Energy and economic indicators

							1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	2016	2030	2050	2050
GDP ($2010 billion)	6,632	8,648	11,887	27,973	52,582	77,674	105,279	4.6	4.6	3.5	4.0
Population (million)	3,457	4,216	4,963	6,152	7,156	7,781	8,324	1.5	1.1	0.8	0.9
CO_2 emissions (Mt)	6,637	8,888	9,841	19,564	25,134	28,577	30,788	3.1	1.8	1.0	1.3
GDP per capita ($2010 thousand)	1.9	2.1	2.4	4.5	7.3	10.0	13	3.1	3.5	2.8	3.1
Primary energy consump. per capita (toe)	0.9	1.0	0.9	1.3	1.5	1.6	1.6	1.2	1.0	0.4	0.7
Primary energy consumption per GDP[*2]	448	468	376	290	205	160	130	-1.8	-2.4	-2.2	-2.3
CO_2 emissions per GDP[*3]	1,001	1,028	828	699	478	368	292	-1.5	-2.7	-2.4	-2.5
CO_2 per primary energy consumption[*4]	2.2	2.2	2.2	2.4	2.3	2.3	2.2	0.4	-0.2	-0.2	-0.2

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A45 | World [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	7,208	8,774	10,036	13,761	15,834	16,650	16,994	100	100	100	1.7	1.0	0.4	0.6
Coal	1,783	2,220	2,316	3,731	3,646	3,391	2,968	25	27	17	2.0	-0.2	-1.0	-0.7
Oil	3,105	3,234	3,663	4,390	4,681	4,662	4,543	37	32	27	1.2	0.5	-0.1	0.1
Natural gas	1,232	1,664	2,072	3,035	3,761	4,140	4,274	19	22	25	2.3	1.5	0.6	1.0
Nuclear	186	526	675	680	1,008	1,246	1,481	6.0	4.9	8.7	1.0	2.9	1.9	2.3
Hydro	148	184	225	349	425	466	501	2.1	2.5	2.9	2.5	1.4	0.8	1.1
Geothermal	12	34	52	81	242	339	430	0.4	0.6	2.5	3.4	8.2	2.9	5.1
Solar, wind, etc.	0.1	2.5	8.0	145	508	810	1,175	-	1.1	6.9	17.0	9.4	4.3	6.3
Biomass and waste	742	909	1,022	1,349	1,562	1,595	1,620	10	9.8	9.5	1.5	1.0	0.2	0.5

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	5,368	6,271	7,035	9,555	10,863	11,333	11,546	100	100	100	1.6	0.9	0.3	0.6
Industry	1,766	1,804	1,868	2,753	3,106	3,258	3,278	29	29	28	1.6	0.9	0.3	0.5
Transport	1,246	1,570	1,958	2,748	2,997	3,001	2,985	25	29	26	2.2	0.6	0.0	0.2
Buildings, etc.	2,002	2,417	2,596	3,185	3,663	3,817	3,904	39	33	34	1.1	1.0	0.3	0.6
Non-energy use	354	480	614	870	1,098	1,256	1,379	7.6	9.1	12	2.3	1.7	1.1	1.4
Coal	703	752	542	1,036	1,020	980	907	12	11	7.9	1.2	-0.1	-0.6	-0.4
Oil	2,446	2,605	3,122	3,908	4,235	4,250	4,186	42	41	36	1.6	0.6	-0.1	0.2
Natural gas	815	945	1,118	1,440	1,747	1,857	1,889	15	15	16	1.6	1.4	0.4	0.8
Electricity	586	834	1,089	1,794	2,446	2,889	3,278	13	19	28	3.0	2.2	1.5	1.8
Heat	121	336	248	283	285	276	261	5.4	3.0	2.3	-0.7	0.0	-0.4	-0.2
Hydrogen	-	-	-	-	0.6	2.2	6.2	-	-	0.1	n.a.	n.a.	12.9	n.a.
Renewables	698	799	916	1,095	1,130	1,080	1,018	13	11	8.8	1.2	0.2	-0.5	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	8,283	11,852	15,441	24,973	33,592	38,835	43,245	100	100	100	2.9	2.1	1.3	1.6
Coal	3,137	4,430	6,001	9,594	9,665	8,869	7,577	37	38	18	3.0	0.1	-1.2	-0.7
Oil	1,659	1,323	1,212	931	796	689	512	11	3.7	1.2	-1.3	-1.1	-2.2	-1.7
Natural gas	999	1,750	2,747	5,794	7,825	9,188	9,929	15	23	23	4.7	2.2	1.2	1.6
Nuclear	713	2,013	2,591	2,606	3,868	4,783	5,685	17	10	13	1.0	2.9	1.9	2.3
Hydro	1,717	2,144	2,618	4,061	4,940	5,415	5,824	18	16	13	2.5	1.4	0.8	1.1
Geothermal	14	36	52	82	268	371	468	0.3	0.3	1.1	3.2	8.8	2.8	5.3
Solar PV	-	0.1	1.0	328	1,677	2,750	3,884	-	1.3	9.0	37.3	12.4	4.3	7.5
Wind	-	3.9	31	958	3,186	4,864	6,762	-	3.8	16	23.6	9.0	3.8	5.9
CSP and marine	0.5	1.2	1.1	12	190	422	814	-	-	1.9	9.1	22.2	7.5	13.3
Biomass and waste	44	130	164	571	1,141	1,448	1,755	1.1	2.3	4.1	5.9	5.1	2.2	3.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	37	37	37	37	0.2	0.1	0.1	2.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	28,090	37,882	49,957	77,321	116,562	153,030	191,975	2.8	3.0	2.5	2.7
Population (million)	4,437	5,281	6,113	7,433	8,514	9,172	9,733	1.3	1.0	0.7	0.8
CO_2 emissions (Mt)	17,808	20,479	23,113	32,353	33,335	31,513	28,714	1.8	0.2	-0.7	-0.4
GDP per capita ($2010 thousand)	6.3	7.2	8.2	10	14	17	20	1.4	2.0	1.8	1.9
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.9	1.8	1.7	0.4	0.0	-0.3	-0.2
Primary energy consumption per GDP[*2]	257	232	201	178	136	109	89	-1.0	-1.9	-2.1	-2.0
CO_2 emissions per GDP[*3]	634	541	463	418	286	206	150	-1.0	-2.7	-3.2	-3.0
CO_2 per primary energy consumption[*4]	2.5	2.3	2.3	2.4	2.1	1.9	1.7	0.0	-0.8	-1.1	-1.0

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A46 | Asia [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	1,439	2,110	2,887	5,497	6,997	7,622	7,917	100	100	100	3.8	1.7	0.6	1.1
Coal	466	787	1,036	2,685	2,851	2,761	2,502	37	49	32	4.8	0.4	-0.6	-0.2
Oil	477	618	916	1,367	1,711	1,807	1,815	29	25	23	3.1	1.6	0.3	0.8
Natural gas	51	116	233	567	941	1,167	1,316	5.5	10	17	6.3	3.7	1.7	2.5
Nuclear	25	77	132	122	398	583	765	3.6	2.2	9.7	1.8	8.8	3.3	5.6
Hydro	20	32	41	138	182	205	221	1.5	2.5	2.8	5.8	2.0	1.0	1.4
Geothermal	2.6	8.2	23	40	122	179	231	0.4	0.7	2.9	6.3	8.4	3.2	5.3
Solar, wind, etc.	-	1.2	2.1	62	229	351	484	0.1	1.1	6.1	16.2	9.8	3.8	6.2
Biomass and waste	397	471	503	517	563	569	582	22	9.4	7.3	0.4	0.6	0.2	0.4

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,129	1,556	1,991	3,709	4,592	4,950	5,123	100	100	100	3.4	1.5	0.5	1.0
Industry	383	514	647	1,511	1,726	1,796	1,800	33	41	35	4.2	1.0	0.2	0.5
Transport	124	184	318	661	892	947	968	12	18	19	5.1	2.2	0.4	1.1
Buildings, etc.	569	741	842	1,162	1,475	1,624	1,715	48	31	33	1.7	1.7	0.8	1.2
Non-energy use	54	117	185	375	499	583	640	7.5	10	12	4.6	2.1	1.3	1.6
Coal	301	424	373	899	879	841	778	27	24	15	2.9	-0.2	-0.6	-0.4
Oil	326	459	734	1,204	1,547	1,647	1,670	29	32	33	3.8	1.8	0.4	1.0
Natural gas	21	47	88	266	440	511	544	3.0	7.2	11	6.9	3.6	1.1	2.1
Electricity	88	156	278	784	1,193	1,450	1,668	10	21	33	6.4	3.0	1.7	2.2
Heat	7.5	14	30	96	106	109	104	0.9	2.6	2.0	7.6	0.7	-0.1	0.2
Hydrogen	-	-	-	-	0.3	1.1	3.0	-	-	0.1	n.a.	n.a.	13.0	n.a.
Renewables	386	456	488	459	427	391	356	29	12	7.0	0.0	-0.5	-0.9	-0.7

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,196	2,240	3,983	10,768	16,250	19,345	21,851	100	100	100	6.2	3.0	1.5	2.1
Coal	298	869	1,990	6,443	7,393	7,257	6,617	39	60	30	8.0	1.0	-0.6	0.1
Oil	476	434	390	233	169	135	89	19	2.2	0.4	-2.4	-2.3	-3.2	-2.8
Natural gas	90	237	559	1,340	2,242	3,023	3,705	11	12	17	6.9	3.7	2.5	3.0
Nuclear	97	294	505	468	1,529	2,236	2,935	13	4.3	13	1.8	8.8	3.3	5.6
Hydro	232	369	478	1,603	2,118	2,382	2,565	16	15	12	5.8	2.0	1.0	1.4
Geothermal	3.0	8.4	20	24	80	116	151	0.4	0.2	0.7	4.2	8.8	3.2	5.5
Solar PV	-	0.1	0.6	152	974	1,602	2,187	-	1.4	10	34.4	14.2	4.1	8.2
Wind	-	-	2.4	294	1,285	1,985	2,812	-	2.7	13	41.7	11.1	4.0	6.9
CSP and marine	-	-	-	0.5	12	28	62	-	-	0.3	18.2	25.2	8.4	15.0
Biomass and waste	-	9.5	17	187	425	559	705	0.4	1.7	3.2	12.1	6.0	2.6	4.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	23	23	23	23	0.9	0.2	0.1	0.6	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	4,441	7,560	11,025	23,349	42,947	61,820	81,967	4.4	4.4	3.3	3.8
Population (million)	2,440	2,933	3,410	4,035	4,439	4,601	4,665	1.2	0.7	0.2	0.4
CO_2 emissions (Mt)	3,105	4,632	6,720	14,795	16,704	16,369	15,090	4.6	0.9	-0.5	0.1
GDP per capita ($2010 thousand)	1.8	2.6	3.2	5.8	9.7	13	18	3.2	3.7	3.0	3.3
Primary energy consump. per capita (toe)	0.6	0.7	0.8	1.4	1.6	1.7	1.7	2.5	1.0	0.4	0.6
Primary energy consumption per GDP[*2]	324	279	262	235	163	123	97	-0.7	-2.6	-2.6	-2.6
CO_2 emissions per GDP[*3]	699	613	609	634	389	265	184	0.1	-3.4	-3.7	-3.6
CO_2 per primary energy consumption[*4]	2.2	2.2	2.3	2.7	2.4	2.1	1.9	0.8	-0.9	-1.1	-1.0

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A47 | China [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	598	874	1,130	2,958	3,427	3,503	3,343	100	100	100	4.8	1.1	-0.1	0.4
Coal	313	531	665	1,916	1,791	1,578	1,240	61	65	37	5.1	-0.5	-1.8	-1.3
Oil	89	119	221	545	678	657	587	14	18	18	6.0	1.6	-0.7	0.2
Natural gas	12	13	21	171	365	455	490	1.5	5.8	15	10.5	5.6	1.5	3.1
Nuclear	-	-	4.4	56	188	308	427	-	1.9	13	n.a.	9.1	4.2	6.2
Hydro	5.0	11	19	100	122	132	135	1.2	3.4	4.0	8.9	1.4	0.5	0.9
Geothermal	-	-	1.7	9.4	12	14	14	-	0.3	0.4	n.a.	1.9	0.7	1.2
Solar, wind, etc.	-	-	1.0	49	156	223	295	-	1.7	8.8	32.4	8.6	3.2	5.4
Biomass and waste	180	200	198	113	117	137	156	23	3.8	4.7	-2.2	0.2	1.4	0.9

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	487	658	781	1,969	2,260	2,301	2,212	100	100	100	4.3	1.0	-0.1	0.3
Industry	181	234	302	994	950	898	833	36	50	38	5.7	-0.3	-0.7	-0.5
Transport	22	30	84	297	424	416	375	4.6	15	17	9.2	2.6	-0.6	0.7
Buildings, etc.	274	351	338	516	670	736	736	53	26	33	1.5	1.9	0.5	1.0
Non-energy use	10	43	57	162	215	252	269	6.5	8.2	12	5.3	2.0	1.1	1.5
Coal	214	311	274	710	601	525	445	47	36	20	3.2	-1.2	-1.5	-1.4
Oil	59	85	180	495	626	609	546	13	25	25	7.0	1.7	-0.7	0.3
Natural gas	6.4	8.9	12	113	198	226	233	1.3	5.7	11	10.3	4.1	0.8	2.2
Electricity	21	39	89	445	635	733	782	5.9	23	35	9.8	2.6	1.0	1.7
Heat	7.4	13	26	90	99	102	97	2.0	4.6	4.4	7.7	0.7	-0.1	0.2
Hydrogen	-	-	-	-	0.2	0.9	2.6	-	-	0.1	n.a.	n.a.	14.3	n.a.
Renewables	180	200	199	117	100	106	106	30	5.9	4.8	-2.1	-1.1	0.3	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	301	621	1,356	6,187	8,687	9,833	10,313	100	100	100	9.2	2.5	0.9	1.5
Coal	159	441	1,060	4,242	4,277	3,809	2,830	71	69	27	9.1	0.1	-2.0	-1.2
Oil	82	50	47	10	8.6	6.2	3.4	8.1	0.2	-	-5.9	-1.3	-4.5	-3.2
Natural gas	0.7	2.8	5.8	170	634	890	1,002	0.4	2.8	9.7	17.2	9.8	2.3	5.3
Nuclear	-	-	17	213	721	1,183	1,639	-	3.4	16	n.a.	9.1	4.2	6.2
Hydro	58	127	222	1,163	1,414	1,531	1,574	20	19	15	8.9	1.4	0.5	0.9
Geothermal	-	0.1	0.1	0.1	0.5	0.6	0.7	-	-	-	3.1	10.1	2.1	5.3
Solar PV	-	-	-	75	469	698	886	-	1.2	8.6	50.0	14.0	3.2	7.5
Wind	-	-	0.6	237	992	1,479	2,061	-	3.8	20	56.7	10.8	3.7	6.6
CSP and marine	-	-	-	-	3.5	11	29	-	-	0.3	6.9	37.5	11.2	21.4
Biomass and waste	-	-	2.4	76	168	225	288	-	1.2	2.8	n.a.	5.8	2.7	4.0
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	341	830	2,237	9,504	20,603	31,022	40,505	9.8	5.7	3.4	4.4
Population (million)	981	1,135	1,263	1,379	1,416	1,393	1,341	0.8	0.2	-0.3	-0.1
CO_2 emissions (Mt)	1,392	2,136	3,126	9,015	9,042	8,113	6,574	5.7	0.0	-1.6	-0.9
GDP per capita ($2010 thousand)	0.3	0.7	1.8	6.9	15	22	30	9.0	5.5	3.7	4.4
Primary energy consump. per capita (toe)	0.6	0.8	0.9	2.1	2.4	2.5	2.5	4.0	0.9	0.1	0.4
Primary energy consumption per GDP[*2]	1,752	1,053	505	311	166	113	83	-4.6	-4.4	-3.4	-3.8
CO_2 emissions per GDP[*3]	4,079	2,575	1,398	949	439	262	162	-3.8	-5.4	-4.9	-5.1
CO_2 per primary energy consumption[*4]	2.3	2.4	2.8	3.0	2.6	2.3	2.0	0.9	-1.0	-1.5	-1.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A48 | India [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total*1	200	306	441	862	1,436	1,732	1,984	100	100	100	4.1	3.7	1.6	2.5
Coal	44	93	146	380	603	676	735	30	44	37	5.6	3.4	1.0	2.0
Oil	33	61	112	217	375	466	524	20	25	26	5.0	4.0	1.7	2.6
Natural gas	1.3	11	23	47	123	178	226	3.5	5.5	11	5.9	7.1	3.1	4.7
Nuclear	0.8	1.6	4.4	9.9	53	92	130	0.5	1.1	6.6	7.3	12.7	4.6	7.9
Hydro	4.0	6.2	6.4	12	24	31	38	2.0	1.4	1.9	2.5	5.2	2.4	3.5
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar, wind, etc.	-	-	0.2	5.8	51	88	128	-	0.7	6.4	27.5	16.8	4.7	9.5
Biomass and waste	116	133	149	192	207	200	203	44	22	10	1.4	0.5	-0.1	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	174	243	314	572	940	1,141	1,306	100	100	100	3.4	3.6	1.7	2.5
Industry	41	67	83	193	361	430	468	27	34	36	4.2	4.6	1.3	2.6
Transport	17	21	32	90	156	198	228	8.5	16	17	5.8	4.0	1.9	2.8
Buildings, etc.	110	142	172	243	335	399	472	59	43	36	2.1	2.3	1.7	2.0
Non-energy use	5.7	13	27	46	88	115	137	5.5	8.1	10	4.9	4.7	2.3	3.2
Coal	25	38	33	99	173	204	216	16	17	17	3.7	4.1	1.1	2.3
Oil	27	50	94	182	330	416	473	21	32	36	5.1	4.3	1.8	2.8
Natural gas	0.7	5.6	9.7	32	72	94	107	2.3	5.6	8.2	6.9	5.9	2.0	3.6
Electricity	7.8	18	32	95	217	304	402	7.6	17	31	6.5	6.1	3.1	4.3
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	0.1	0.2	-	-	-	n.a.	n.a.	12.4	n.a.
Renewables	114	130	144	164	147	124	108	54	29	8.2	0.9	-0.8	-1.6	-1.2

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	120	293	570	1,478	3,187	4,210	5,351	100	100	100	6.4	5.6	2.6	3.9
Coal	61	192	390	1,105	1,756	1,913	2,135	65	75	40	7.0	3.4	1.0	2.0
Oil	8.8	13	29	23	26	20	12	4.5	1.6	0.2	2.2	0.7	-3.9	-2.1
Natural gas	0.6	10.0	56	71	251	439	665	3.4	4.8	12	7.9	9.4	5.0	6.8
Nuclear	3.0	6.1	17	38	203	352	500	2.1	2.6	9.3	7.3	12.7	4.6	7.9
Hydro	47	72	74	138	280	364	448	24	9.3	8.4	2.5	5.2	2.4	3.5
Geothermal	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Solar PV	-	-	-	14	311	550	762	-	1.0	14	n.a.	24.7	4.6	12.4
Wind	-	-	1.7	45	240	408	604	-	3.0	11	32.1	12.7	4.7	7.9
CSP and marine	-	-	-	-	5.1	11	22	-	-	0.4	n.a.	n.a.	7.6	n.a.
Biomass and waste	-	-	1.3	44	115	154	204	-	3.0	3.8	n.a.	7.2	2.9	4.6
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	271	465	800	2,456	6,243	10,407	16,104	6.6	6.9	4.9	5.7
Population (million)	697	870	1,053	1,324	1,513	1,605	1,659	1.6	1.0	0.5	0.7
CO_2 emissions (Mt)	258	529	885	2,078	3,470	3,972	4,283	5.4	3.7	1.1	2.1
GDP per capita ($2010 thousand)	0.4	0.5	0.8	1.9	4.1	6.5	9.7	4.9	5.9	4.4	5.0
Primary energy consump. per capita (toe)	0.3	0.4	0.4	0.7	0.9	1.1	1.2	2.4	2.7	1.2	1.8
Primary energy consumption per GDP*2	739	658	551	351	230	166	123	-2.4	-3.0	-3.1	-3.0
CO_2 emissions per GDP*3	953	1,138	1,106	846	556	382	266	-1.1	-3.0	-3.6	-3.3
CO_2 per primary energy consumption*4	1.3	1.7	2.0	2.4	2.4	2.3	2.2	1.3	0.0	-0.6	-0.3

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A49 | Japan [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total*1	345	438	518	426	418	385	352	100	100	100	-0.1	-0.1	-0.9	-0.6
Coal	60	76	97	114	97	84	66	17	27	19	1.6	-1.2	-1.9	-1.6
Oil	234	250	255	177	135	114	96	57	42	27	-1.3	-1.9	-1.7	-1.8
Natural gas	21	44	66	102	83	77	69	10	24	19	3.3	-1.4	-1.0	-1.2
Nuclear	22	53	84	4.7	60	56	56	12	1.1	16	-8.9	20.0	-0.4	7.6
Hydro	7.6	7.6	7.3	6.8	7.7	7.8	7.9	1.7	1.6	2.2	-0.4	0.9	0.1	0.4
Geothermal	0.8	1.6	3.1	2.3	6.4	11	15	0.4	0.5	4.3	1.5	7.4	4.5	5.7
Solar, wind, etc.	-	1.2	0.8	5.1	9.1	14	19	0.3	1.2	5.3	5.8	4.2	3.7	3.9
Biomass and waste	-	4.6	4.9	14	19	21	24	1.0	3.2	6.8	4.4	2.3	1.1	1.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	232	288	331	294	271	249	230	100	100	100	0.1	-0.6	-0.8	-0.7
Industry	91	106	97	82	78	76	73	37	28	32	-1.0	-0.3	-0.3	-0.3
Transport	54	68	86	72	53	44	37	24	24	16	0.2	-2.1	-1.7	-1.9
Buildings, etc.	58	78	106	104	103	95	85	27	35	37	1.1	0.0	-1.0	-0.6
Non-energy use	28	36	41	37	36	35	34	12	13	15	0.2	-0.2	-0.4	-0.3
Coal	25	27	21	21	19	18	16	9.5	7.3	7.0	-0.9	-0.7	-0.9	-0.8
Oil	157	177	202	150	121	103	88	61	51	38	-0.6	-1.5	-1.6	-1.6
Natural gas	5.8	15	22	32	35	33	30	5.1	11	13	3.0	0.7	-0.8	-0.2
Electricity	44	65	81	83	89	89	87	23	28	38	1.0	0.5	-0.1	0.1
Heat	0.1	0.2	0.5	0.5	0.4	0.4	0.3	0.1	0.2	0.1	3.7	-1.0	-1.5	-1.3
Hydrogen	-	-	-	-	0.1	0.1	0.2	-	-	0.1	n.a.	n.a.	7.0	n.a.
Renewables	-	3.9	3.8	6.7	6.5	6.4	7.4	1.4	2.3	3.2	2.1	-0.2	0.6	0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	573	861	1,058	1,052	1,119	1,121	1,098	100	100	100	0.8	0.4	-0.1	0.1
Coal	55	123	230	349	286	241	181	14	33	16	4.1	-1.4	-2.3	-1.9
Oil	265	248	140	84	31	18	5.9	29	8.0	0.5	-4.1	-6.8	-8.0	-7.5
Natural gas	81	168	248	406	290	286	270	20	39	25	3.5	-2.4	-0.4	-1.2
Nuclear	83	202	322	18	232	215	215	24	1.7	20	-8.9	20.0	-0.4	7.6
Hydro	88	88	84	79	89	91	91	10	7.5	8.3	-0.4	0.9	0.1	0.4
Geothermal	0.9	1.7	3.3	2.5	7.2	12	18	0.2	0.2	1.6	1.4	7.8	4.5	5.9
Solar PV	-	0.1	0.4	51	84	130	168	-	4.8	15	29.1	3.6	3.5	3.6
Wind	-	-	0.1	6.0	20	35	50	-	0.6	4.5	n.a.	9.1	4.6	6.4
CSP and marine	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Biomass and waste	-	8.9	10	34	58	71	79	1.0	3.2	7.2	5.2	4.0	1.5	2.5
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	21	21	21	21	2.3	2.0	2.0	0.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	2,977	4,683	5,349	6,053	6,808	7,353	7,885	1.0	0.8	0.7	0.8
Population (million)	117	124	127	127	121	115	108	0.1	-0.4	-0.6	-0.5
CO_2 emissions (Mt)	908	1,046	1,145	1,138	904	778	642	0.3	-1.6	-1.7	-1.7
GDP per capita ($2010 thousand)	25	38	42	48	56	64	73	0.9	1.2	1.3	1.3
Primary energy consump. per capita (toe)	3.0	3.5	4.1	3.4	3.5	3.4	3.3	-0.2	0.2	-0.3	-0.1
Primary energy consumption per GDP*2	116	94	97	70	61	52	45	-1.1	-1.0	-1.6	-1.3
CO_2 emissions per GDP*3	305	223	214	188	133	106	81	-0.7	-2.4	-2.4	-2.4
CO_2 per primary energy consumption*4	2.6	2.4	2.2	2.7	2.2	2.0	1.8	0.4	-1.5	-0.8	-1.1

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A50 | ASEAN [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	142	233	379	643	998	1,247	1,460	100	100	100	4.0	3.2	1.9	2.4
Coal	3.6	13	32	120	209	269	316	5.4	19	22	9.1	4.0	2.1	2.9
Oil	58	89	153	220	294	343	389	38	34	27	3.6	2.1	1.4	1.7
Natural gas	8.6	30	74	139	212	259	298	13	22	20	6.1	3.1	1.7	2.3
Nuclear	-	-	-	-	14	49	76	-	-	5.2	n.a.	n.a.	9.0	n.a.
Hydro	0.8	2.3	4.1	11	18	20	22	1.0	1.7	1.5	6.1	3.5	1.1	2.1
Geothermal	1.8	6.6	18	28	103	153	200	2.8	4.3	14	5.7	9.8	3.4	6.0
Solar, wind, etc.	-	-	-	0.6	6.4	13	22	-	0.1	1.5	n.a.	19.1	6.5	11.5
Biomass and waste	70	93	98	123	139	137	132	40	19	9.0	1.1	0.9	-0.3	0.2

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	112	173	270	451	629	739	835	100	100	100	3.7	2.4	1.4	1.8
Industry	22	43	75	129	201	246	275	25	29	33	4.3	3.2	1.6	2.3
Transport	17	32	61	122	164	192	226	19	27	27	5.2	2.1	1.6	1.8
Buildings, etc.	71	87	113	148	189	207	221	50	33	26	2.1	1.8	0.8	1.2
Non-energy use	2.4	11	21	52	76	95	114	6.3	12	14	6.2	2.7	2.1	2.3
Coal	2.1	6.1	13	35	51	58	61	3.5	7.8	7.3	7.0	2.6	0.9	1.6
Oil	41	67	123	204	276	325	371	38	45	44	4.4	2.2	1.5	1.8
Natural gas	2.5	7.5	17	37	62	76	83	4.4	8.2	10.0	6.3	3.8	1.5	2.4
Electricity	4.7	11	28	73	137	188	239	6.4	16	29	7.5	4.6	2.8	3.5
Heat	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Hydrogen	-	-	-	-	-	-	0.1	-	-	-	n.a.	n.a.	7.9	n.a.
Renewables	61	82	89	102	102	92	80	47	23	9.6	0.8	0.0	-1.2	-0.7

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	62	154	370	926	1,753	2,400	3,040	100	100	100	7.1	4.7	2.8	3.6
Coal	3.0	28	79	339	679	893	1,098	18	37	36	10.1	5.1	2.4	3.5
Oil	47	66	72	25	21	19	11	43	2.7	0.4	-3.7	-1.2	-3.0	-2.2
Natural gas	0.7	26	154	383	588	725	889	17	41	29	10.9	3.1	2.1	2.5
Nuclear	-	-	-	-	52	187	292	-	-	9.6	n.a.	n.a.	9.0	n.a.
Hydro	9.8	27	47	128	208	238	259	18	14	8.5	6.1	3.5	1.1	2.1
Geothermal	2.1	6.6	16	22	71	102	131	4.3	2.3	4.3	4.7	8.8	3.1	5.4
Solar PV	-	-	-	4.9	63	135	226	-	0.5	7.4	n.a.	20.0	6.6	11.9
Wind	-	-	-	1.5	11	22	33	-	0.2	1.1	n.a.	15.2	5.7	9.5
CSP and marine	-	-	-	-	0.1	0.2	0.5	-	-	-	n.a.	n.a.	9.9	n.a.
Biomass and waste	-	0.6	1.0	23	60	79	100	0.4	2.5	3.3	15.1	7.0	2.6	4.4
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	440	741	1,180	2,607	5,042	7,503	10,546	5.0	4.8	3.8	4.2
Population (million)	346	430	506	618	700	740	765	1.4	0.9	0.4	0.6
CO_2 emissions (Mt)	188	348	676	1,298	1,886	2,037	2,112	5.2	2.7	0.6	1.4
GDP per capita ($2010 thousand)	1.3	1.7	2.3	4.2	7.2	10	14	3.5	3.9	3.3	3.5
Primary energy consump. per capita (toe)	0.4	0.5	0.7	1.0	1.4	1.7	1.9	2.5	2.3	1.5	1.8
Primary energy consumption per GDP[*2]	323	314	322	247	198	166	138	-0.9	-1.6	-1.8	-1.7
CO_2 emissions per GDP[*3]	426	469	573	498	374	271	200	0.2	-2.0	-3.1	-2.6
CO_2 per primary energy consumption[*4]	1.3	1.5	1.8	2.0	1.9	1.6	1.4	1.2	-0.5	-1.3	-1.0

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A51 | United States [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	1,805	1,915	2,274	2,167	2,056	1,914	1,764	100	100	100	0.5	-0.4	-0.8	-0.6
Coal	376	460	534	342	227	140	66	24	16	3.7	-1.1	-2.9	-6.0	-4.7
Oil	797	757	871	787	652	542	452	40	36	26	0.2	-1.3	-1.8	-1.6
Natural gas	477	438	548	653	675	641	546	23	30	31	1.5	0.2	-1.1	-0.5
Nuclear	69	159	208	219	193	187	178	8.3	10	10	1.2	-0.9	-0.4	-0.6
Hydro	24	23	22	23	25	26	26	1.2	1.1	1.5	0.0	0.7	0.1	0.3
Geothermal	4.6	14	13	9.2	34	44	52	0.7	0.4	2.9	-1.6	9.8	2.1	5.2
Solar, wind, etc.	-	0.3	2.1	26	108	183	279	-	1.2	16	18.5	10.6	4.8	7.2
Biomass and waste	54	62	73	102	136	148	160	3.3	4.7	9.1	1.9	2.1	0.8	1.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,311	1,294	1,546	1,515	1,444	1,347	1,248	100	100	100	0.6	-0.3	-0.7	-0.6
Industry	387	284	332	264	264	253	228	22	17	18	-0.3	0.0	-0.7	-0.4
Transport	425	488	588	622	536	465	418	38	41	34	0.9	-1.1	-1.2	-1.2
Buildings, etc.	397	403	473	493	493	472	447	31	33	36	0.8	0.0	-0.5	-0.3
Non-energy use	102	119	153	136	152	157	154	9.2	9.0	12	0.5	0.8	0.1	0.4
Coal	56	56	33	18	15	13	11	4.3	1.2	0.9	-4.4	-0.9	-1.6	-1.3
Oil	689	683	793	744	622	521	438	53	49	35	0.3	-1.3	-1.7	-1.5
Natural gas	338	303	360	336	325	304	274	23	22	22	0.4	-0.2	-0.8	-0.6
Electricity	174	226	301	327	379	401	410	18	22	33	1.4	1.1	0.4	0.7
Heat	-	2.2	5.3	6.6	5.5	4.8	4.0	0.2	0.4	0.3	4.4	-1.3	-1.5	-1.4
Hydrogen	-	-	-	-	0.1	0.7	2.4	-	-	0.2	n.a.	n.a.	15.9	n.a.
Renewables	54	23	54	83	97	101	107	1.8	5.5	8.6	5.1	1.1	0.5	0.8

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	2,427	3,203	4,026	4,300	4,958	5,207	5,285	100	100	100	1.1	1.0	0.3	0.6
Coal	1,243	1,700	2,129	1,354	893	518	196	53	31	3.7	-0.9	-2.9	-7.3	-5.5
Oil	263	131	118	35	22	12	4.1	4.1	0.8	0.1	-5.0	-3.1	-8.1	-6.1
Natural gas	370	382	634	1,418	1,744	1,697	1,315	12	33	25	5.2	1.5	-1.4	-0.2
Nuclear	266	612	798	840	742	717	683	19	20	13	1.2	-0.9	-0.4	-0.6
Hydro	279	273	253	270	295	298	300	8.5	6.3	5.7	0.0	0.7	0.1	0.3
Geothermal	5.4	16	15	19	70	91	108	0.5	0.4	2.0	0.6	10.0	2.2	5.3
Solar PV	-	-	0.2	47	214	353	510	-	1.1	9.7	44.9	11.5	4.4	7.3
Wind	-	3.1	5.7	229	714	1,114	1,564	0.1	5.3	30	18.1	8.4	4.0	5.8
CSP and marine	-	0.7	0.5	3.7	101	208	376	-	0.1	7.1	6.8	26.6	6.8	14.6
Biomass and waste	0.5	86	72	79	158	192	224	2.7	1.8	4.2	-0.3	5.1	1.8	3.1
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	-	-	5.6	5.6	5.6	5.6	-	0.1	0.1	n.a.	0.0	0.0	0.0

Energy and economic indicators

								1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	2016	2030	2050	2050
GDP ($2010 billion)	6,529	9,064	12,713	16,920	22,637	27,647	32,825	2.4	2.1	1.9	2.0
Population (million)	227	250	282	323	356	375	391	1.0	0.7	0.5	0.6
CO_2 emissions (Mt)	4,620	4,817	5,700	4,870	3,902	3,035	2,276	0.0	-1.6	-2.7	-2.2
GDP per capita ($2010 thousand)	29	36	45	52	64	74	84	1.4	1.4	1.4	1.4
Primary energy consump. per capita (toe)	7.9	7.7	8.1	6.7	5.8	5.1	4.5	-0.5	-1.1	-1.2	-1.2
Primary energy consumption per GDP[*2]	276	211	179	128	91	69	54	-1.9	-2.4	-2.6	-2.5
CO_2 emissions per GDP[*3]	708	531	448	288	172	110	69	-2.3	-3.6	-4.5	-4.1
CO_2 per primary energy consumption[*4]	2.6	2.5	2.5	2.2	1.9	1.6	1.3	-0.4	-1.2	-1.9	-1.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A52 | European Union [Advanced Technologies Scenario]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	n.a.	1,646	1,695	1,599	1,507	1,385	1,280	100	100	100	-0.1	-0.4	-0.8	-0.7
Coal	n.a.	454	321	241	161	110	72	28	15	5.6	-2.4	-2.9	-3.9	-3.5
Oil	n.a.	608	625	522	431	350	287	37	33	22	-0.6	-1.4	-2.0	-1.7
Natural gas	n.a.	297	396	383	375	331	270	18	24	21	1.0	-0.2	-1.6	-1.0
Nuclear	n.a.	207	246	219	220	228	244	13	14	19	0.2	0.0	0.5	0.3
Hydro	n.a.	25	31	30	31	32	32	1.5	1.9	2.5	0.7	0.2	0.2	0.2
Geothermal	n.a.	3.2	4.6	6.7	11	12	12	0.2	0.4	1.0	2.9	3.4	0.8	1.9
Solar, wind, etc.	n.a.	0.3	2.4	40	93	131	168	-	2.5	13	20.6	6.3	3.0	4.4
Biomass and waste	n.a.	48	67	155	184	188	192	2.9	9.7	15	4.7	1.2	0.2	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	n.a.	1,134	1,179	1,138	1,085	990	905	100	100	100	0.0	-0.3	-0.9	-0.7
Industry	n.a.	345	308	257	252	239	221	30	23	24	-1.1	-0.1	-0.6	-0.4
Transport	n.a.	259	303	319	262	213	180	23	28	20	0.8	-1.4	-1.9	-1.7
Buildings, etc.	n.a.	430	454	463	469	437	406	38	41	45	0.3	0.1	-0.7	-0.4
Non-energy use	n.a.	100	113	98	102	101	97	8.8	8.6	11	-0.1	0.3	-0.2	0.0
Coal	n.a.	120	51	34	33	29	26	11	3.0	2.8	-4.7	-0.4	-1.2	-0.9
Oil	n.a.	506	543	471	392	319	261	45	41	29	-0.3	-1.3	-2.0	-1.7
Natural gas	n.a.	227	272	252	252	232	211	20	22	23	0.4	0.0	-0.9	-0.5
Electricity	n.a.	186	217	239	266	279	287	16	21	32	1.0	0.8	0.4	0.5
Heat	n.a.	55	45	48	45	39	34	4.9	4.2	3.8	-0.5	-0.5	-1.4	-1.0
Hydrogen	n.a.	-	-	-	-	0.1	0.2	-	-	-	n.a.	n.a.	9.1	n.a.
Renewables	n.a.	40	50	93	98	92	86	3.5	8.2	9.5	3.3	0.4	-0.7	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	n.a.	2,577	3,006	3,228	3,618	3,787	3,907	100	100	100	0.9	0.8	0.4	0.6
Coal	n.a.	1,050	968	736	466	280	131	41	23	3.4	-1.4	-3.2	-6.1	-4.9
Oil	n.a.	224	181	60	33	17	5.5	8.7	1.8	0.1	-5.0	-4.1	-8.6	-6.8
Natural gas	n.a.	193	480	611	582	463	244	7.5	19	6.2	4.5	-0.3	-4.3	-2.7
Nuclear	n.a.	795	945	840	844	875	936	31	26	24	0.2	0.0	0.5	0.3
Hydro	n.a.	290	357	350	360	367	374	11	11	9.6	0.7	0.2	0.2	0.2
Geothermal	n.a.	3.2	4.8	6.6	11	12	13	0.1	0.2	0.3	2.8	3.7	0.8	2.0
Solar PV	n.a.	-	0.1	105	254	339	421	-	3.3	11	41.8	6.5	2.6	4.2
Wind	n.a.	0.8	22	303	703	980	1,251	-	9.4	32	25.8	6.2	2.9	4.3
CSP and marine	n.a.	0.5	0.5	6.1	39	73	110	-	0.2	2.8	10.1	14.1	5.3	8.9
Biomass and waste	n.a.	20	46	206	322	375	417	0.8	6.4	11	9.5	3.2	1.3	2.1
Hydrogen	n.a.	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	n.a.	0.2	1.4	5.0	4.3	4.3	4.3	-	0.2	0.1	12.9	-1.0	0.0	-0.4

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	n.a.	11,895	14,789	18,309	23,323	26,643	29,798	1.7	1.7	1.2	1.4
Population (million)	n.a.	478	488	511	524	526	523	0.3	0.2	0.0	0.1
CO_2 emissions (Mt)	n.a.	4,018	3,798	3,195	2,510	1,967	1,497	-0.9	-1.7	-2.6	-2.2
GDP per capita ($2010 thousand)	n.a.	25	30	36	45	51	57	1.4	1.6	1.2	1.4
Primary energy consump. per capita (toe)	n.a.	3.4	3.5	3.1	2.9	2.6	2.4	-0.4	-0.6	-0.8	-0.7
Primary energy consumption per GDP[*2]	n.a.	138	115	87	65	52	43	-1.8	-2.1	-2.0	-2.1
CO_2 emissions per GDP[*3]	n.a.	338	257	175	108	74	50	-2.5	-3.4	-3.7	-3.6
CO_2 per primary energy consumption[*4]	n.a.	2.4	2.2	2.0	1.7	1.4	1.2	-0.8	-1.3	-1.8	-1.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A53 | World [No New Coal-fired Power Plant (Natural Gas Substitution) Case]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	7,208	8,774	10,036	13,761	16,377	17,835	18,879	100	100	100	1.7	1.3	0.7	0.9
Coal	1,783	2,220	2,316	3,731	3,502	3,150	2,693	25	27	14	2.0	-0.5	-1.3	-1.0
Oil	3,105	3,234	3,663	4,390	5,121	5,496	5,715	37	32	30	1.2	1.1	0.6	0.8
Natural gas	1,232	1,664	2,072	3,035	4,403	5,429	6,344	19	22	34	2.3	2.7	1.8	2.2
Nuclear	186	526	675	680	814	856	911	6.0	4.9	4.8	1.0	1.3	0.6	0.9
Hydro	148	184	225	349	425	466	501	2.1	2.5	2.7	2.5	1.4	0.8	1.1
Geothermal	12	34	52	81	182	233	281	0.4	0.6	1.5	3.4	6.0	2.2	3.7
Solar, wind, etc.	0.1	2.5	8.0	145	387	568	757	-	1.1	4.0	17.0	7.3	3.4	5.0
Biomass and waste	742	909	1,022	1,349	1,541	1,634	1,676	10	9.8	8.9	1.5	1.0	0.4	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	5,368	6,271	7,035	9,555	11,307	12,350	13,145	100	100	100	1.6	1.2	0.8	0.9
Industry	1,766	1,804	1,868	2,753	3,214	3,535	3,771	29	29	29	1.6	1.1	0.8	0.9
Transport	1,246	1,570	1,958	2,748	3,245	3,507	3,705	25	29	28	2.2	1.2	0.7	0.9
Buildings, etc.	2,002	2,417	2,596	3,185	3,750	4,052	4,290	39	33	33	1.1	1.2	0.7	0.9
Non-energy use	354	480	614	870	1,098	1,256	1,379	7.6	9.1	10	2.3	1.7	1.1	1.4
Coal	703	752	542	1,036	1,098	1,125	1,110	12	11	8.4	1.2	0.4	0.1	0.2
Oil	2,446	2,605	3,122	3,908	4,599	4,948	5,175	42	41	39	1.6	1.2	0.6	0.8
Natural gas	815	945	1,118	1,440	1,670	1,827	1,955	15	15	15	1.6	1.1	0.8	0.9
Electricity	586	834	1,089	1,794	2,465	2,942	3,410	13	19	26	3.0	2.3	1.6	1.9
Heat	121	336	248	283	288	288	286	5.4	3.0	2.2	-0.7	0.1	0.0	0.0
Hydrogen	-	-	-	-	0.7	1.2	1.3	-	-	-	n.a.	n.a.	3.1	n.a.
Renewables	698	799	916	1,095	1,186	1,218	1,208	13	11	9.2	1.2	0.6	0.1	0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	8,283	11,852	15,441	24,973	34,152	40,269	45,964	100	100	100	2.9	2.3	1.5	1.8
Coal	3,137	4,430	6,001	9,594	8,524	7,006	5,217	37	38	11	3.0	-0.8	-2.4	-1.8
Oil	1,659	1,323	1,212	931	981	991	891	11	3.7	1.9	-1.3	0.4	-0.5	-0.1
Natural gas	999	1,750	2,747	5,794	11,619	16,460	21,285	15	23	46	4.7	5.1	3.1	3.9
Nuclear	713	2,013	2,591	2,606	3,122	3,287	3,496	17	10	7.6	1.0	1.3	0.6	0.9
Hydro	1,717	2,144	2,618	4,061	4,940	5,415	5,824	18	16	13	2.5	1.4	0.8	1.1
Geothermal	14	36	52	82	195	254	307	0.3	0.3	0.7	3.2	6.4	2.3	4.0
Solar PV	-	0.1	1.0	328	1,229	1,923	2,653	-	1.3	5.8	37.3	9.9	3.9	6.3
Wind	-	3.9	31	958	2,446	3,501	4,506	-	3.8	9.8	23.6	6.9	3.1	4.7
CSP and marine	0.5	1.2	1.1	12	119	214	351	-	-	0.8	9.1	18.1	5.6	10.6
Biomass and waste	44	130	164	571	942	1,182	1,399	1.1	2.3	3.0	5.9	3.6	2.0	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	37	37	37	37	0.2	0.1	0.1	2.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	28,090	37,882	49,957	77,321	116,562	153,030	191,975	2.8	3.0	2.5	2.7
Population (million)	4,437	5,281	6,113	7,433	8,514	9,172	9,733	1.3	1.0	0.7	0.8
CO_2 emissions (Mt)	17,808	20,479	23,113	32,353	36,095	37,784	38,452	1.8	0.8	0.3	0.5
GDP per capita ($2010 thousand)	6.3	7.2	8.2	10	14	17	20	1.4	2.0	1.8	1.9
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.9	1.9	1.9	0.4	0.3	0.0	0.1
Primary energy consumption per GDP[*2]	257	232	201	178	140	117	98	-1.0	-1.7	-1.8	-1.7
CO_2 emissions per GDP[*3]	634	541	463	418	310	247	200	-1.0	-2.1	-2.2	-2.1
CO_2 per primary energy consumption[*4]	2.5	2.3	2.3	2.4	2.2	2.1	2.0	0.0	-0.5	-0.4	-0.4

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A54 | Asia [No New Coal-fired Power Plant (Natural Gas Substitution) Case]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	1,439	2,110	2,887	5,497	7,215	8,116	8,721	100	100	100	3.8	2.0	1.0	1.4
Coal	466	787	1,036	2,685	2,729	2,573	2,230	37	49	26	4.8	0.1	-1.0	-0.5
Oil	477	618	916	1,367	1,830	2,063	2,217	29	25	25	3.1	2.1	1.0	1.4
Natural gas	51	116	233	567	1,379	1,982	2,586	5.5	10	30	6.3	6.6	3.2	4.6
Nuclear	25	77	132	122	271	338	404	3.6	2.2	4.6	1.8	5.9	2.0	3.6
Hydro	20	32	41	138	182	205	221	1.5	2.5	2.5	5.8	2.0	1.0	1.4
Geothermal	2.6	8.2	23	40	93	118	143	0.4	0.7	1.6	6.3	6.3	2.2	3.8
Solar, wind, etc.	-	1.2	2.1	62	179	261	340	0.1	1.1	3.9	16.2	7.9	3.3	5.1
Biomass and waste	397	471	503	517	551	575	580	22	9.4	6.6	0.4	0.5	0.3	0.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,129	1,556	1,991	3,709	4,754	5,352	5,797	100	100	100	3.4	1.8	1.0	1.3
Industry	383	514	647	1,511	1,789	1,959	2,086	33	41	36	4.2	1.2	0.8	1.0
Transport	124	184	318	661	969	1,120	1,226	12	18	21	5.1	2.8	1.2	1.8
Buildings, etc.	569	741	842	1,162	1,496	1,690	1,846	48	31	32	1.7	1.8	1.1	1.4
Non-energy use	54	117	185	375	499	583	640	7.5	10	11	4.6	2.1	1.3	1.6
Coal	301	424	373	899	930	942	922	27	24	16	2.9	0.2	0.0	0.1
Oil	326	459	734	1,204	1,645	1,870	2,027	29	32	35	3.8	2.3	1.0	1.5
Natural gas	21	47	88	266	417	502	565	3.0	7.2	9.7	6.9	3.3	1.5	2.2
Electricity	88	156	278	784	1,205	1,484	1,748	10	21	30	6.4	3.1	1.9	2.4
Heat	7.5	14	30	96	109	114	114	0.9	2.6	2.0	7.6	0.9	0.2	0.5
Hydrogen	-	-	-	-	0.2	0.5	0.5	-	-	-	n.a.	n.a.	3.7	n.a.
Renewables	386	456	488	459	447	439	421	29	12	7.3	0.0	-0.2	-0.3	-0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,196	2,240	3,983	10,768	16,566	20,173	23,404	100	100	100	6.2	3.1	1.7	2.3
Coal	298	869	1,990	6,443	6,524	5,868	4,571	39	60	20	8.0	0.1	-1.8	-1.0
Oil	476	434	390	233	209	183	140	19	2.2	0.6	-2.4	-0.8	-2.0	-1.5
Natural gas	90	237	559	1,340	4,540	7,297	10,455	11	12	45	6.9	9.1	4.3	6.2
Nuclear	97	294	505	468	1,041	1,296	1,552	13	4.3	6.6	1.8	5.9	2.0	3.6
Hydro	232	369	478	1,603	2,118	2,382	2,565	16	15	11	5.8	2.0	1.0	1.4
Geothermal	3.0	8.4	20	24	60	77	94	0.4	0.2	0.4	4.2	6.7	2.2	4.1
Solar PV	-	0.1	0.6	152	708	1,123	1,533	-	1.4	6.5	34.4	11.6	3.9	7.0
Wind	-	-	2.4	294	993	1,458	1,892	-	2.7	8.1	41.7	9.1	3.3	5.6
CSP and marine	-	-	-	0.5	7.5	14	26	-	-	0.1	18.2	20.8	6.4	12.1
Biomass and waste	-	9.5	17	187	341	452	554	0.4	1.7	2.4	12.1	4.4	2.5	3.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	23	23	23	23	0.9	0.2	0.1	0.6	0.0	0.0	0.0

Energy and economic indicators

								1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	2016	2030	2050	2050
GDP ($2010 billion)	4,441	7,560	11,025	23,349	42,947	61,820	81,967	4.4	4.4	3.3	3.8
Population (million)	2,440	2,933	3,410	4,035	4,439	4,601	4,665	1.2	0.7	0.2	0.4
CO_2 emissions (Mt)	3,105	4,632	6,720	14,795	17,833	19,080	19,449	4.6	1.3	0.4	0.8
GDP per capita ($2010 thousand)	1.8	2.6	3.2	5.8	9.7	13	18	3.2	3.7	3.0	3.3
Primary energy consump. per capita (toe)	0.6	0.7	0.8	1.4	1.6	1.8	1.9	2.5	1.3	0.7	0.9
Primary energy consumption per GDP[*2]	324	279	262	235	168	131	106	-0.7	-2.4	-2.3	-2.3
CO_2 emissions per GDP[*3]	699	613	609	634	415	309	237	0.1	-3.0	-2.8	-2.8
CO_2 per primary energy consumption[*4]	2.2	2.2	2.3	2.7	2.5	2.4	2.2	0.8	-0.6	-0.5	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A55 | World [No New Coal-fired Power Plant (Renewables Substitution) Case]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	7,208	8,774	10,036	13,761	16,106	17,377	18,257	100	100	100	1.7	1.1	0.6	0.8
Coal	1,783	2,220	2,316	3,731	3,460	3,096	2,632	25	27	14	2.0	-0.5	-1.4	-1.0
Oil	3,105	3,234	3,663	4,390	5,043	5,397	5,603	37	32	31	1.2	1.0	0.5	0.7
Natural gas	1,232	1,664	2,072	3,035	3,967	4,603	5,153	19	22	28	2.3	1.9	1.3	1.6
Nuclear	186	526	675	680	814	856	911	6.0	4.9	5.0	1.0	1.3	0.6	0.9
Hydro	148	184	225	349	425	466	501	2.1	2.5	2.7	2.5	1.4	0.8	1.1
Geothermal	12	34	52	81	183	234	283	0.4	0.6	1.5	3.4	6.0	2.2	3.8
Solar, wind, etc.	0.1	2.5	8.0	145	672	1,086	1,493	-	1.1	8.2	17.0	11.6	4.1	7.1
Biomass and waste	742	909	1,022	1,349	1,542	1,637	1,679	10	9.8	9.2	1.5	1.0	0.4	0.6

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	5,368	6,271	7,035	9,555	11,346	12,427	13,248	100	100	100	1.6	1.2	0.8	1.0
Industry	1,766	1,804	1,868	2,753	3,214	3,535	3,771	29	29	28	1.6	1.1	0.8	0.9
Transport	1,246	1,570	1,958	2,748	3,238	3,497	3,691	25	29	28	2.2	1.2	0.7	0.9
Buildings, etc.	2,002	2,417	2,596	3,185	3,796	4,139	4,407	39	33	33	1.1	1.3	0.7	1.0
Non-energy use	354	480	614	870	1,098	1,256	1,379	7.6	9.1	10	2.3	1.7	1.1	1.4
Coal	703	752	542	1,036	1,064	1,081	1,060	12	11	8.0	1.2	0.2	0.0	0.1
Oil	2,446	2,605	3,122	3,908	4,527	4,857	5,072	42	41	38	1.6	1.1	0.6	0.8
Natural gas	815	945	1,118	1,440	1,789	1,987	2,137	15	15	16	1.6	1.6	0.9	1.2
Electricity	586	834	1,089	1,794	2,485	2,983	3,468	13	19	26	3.0	2.4	1.7	2.0
Heat	121	336	248	283	292	295	295	5.4	3.0	2.2	-0.7	0.2	0.1	0.1
Hydrogen	-	-	-	-	0.7	1.2	1.3	-	-	-	n.a.	n.a.	3.1	n.a.
Renewables	698	799	916	1,095	1,188	1,224	1,215	13	11	9.2	1.2	0.6	0.1	0.3

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	8,283	11,852	15,441	24,973	34,417	40,815	46,737	100	100	100	2.9	2.3	1.5	1.9
Coal	3,137	4,430	6,001	9,594	8,524	7,006	5,217	37	38	11	3.0	-0.8	-2.4	-1.8
Oil	1,659	1,323	1,212	931	981	992	893	11	3.7	1.9	-1.3	0.4	-0.5	-0.1
Natural gas	999	1,750	2,747	5,794	8,587	11,012	13,538	15	23	29	4.7	2.9	2.3	2.5
Nuclear	713	2,013	2,591	2,606	3,122	3,287	3,496	17	10	7.5	1.0	1.3	0.6	0.9
Hydro	1,717	2,144	2,618	4,061	4,940	5,415	5,824	18	16	12	2.5	1.4	0.8	1.1
Geothermal	14	36	52	82	195	254	307	0.3	0.3	0.7	3.2	6.4	2.3	4.0
Solar PV	-	0.1	1.0	328	2,684	4,802	6,959	-	1.3	15	37.3	16.2	4.9	9.4
Wind	-	3.9	31	958	4,287	6,614	8,717	-	3.8	19	23.6	11.3	3.6	6.7
CSP and marine	0.5	1.2	1.1	12	119	214	351	-	-	0.8	9.1	18.1	5.6	10.6
Biomass and waste	44	130	164	571	942	1,182	1,399	1.1	2.3	3.0	5.9	3.6	2.0	2.7
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	22	37	37	37	37	0.2	0.1	0.1	2.3	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	28,090	37,882	49,957	77,321	116,562	153,030	191,975	2.8	3.0	2.5	2.7
Population (million)	4,437	5,281	6,113	7,433	8,514	9,172	9,733	1.3	1.0	0.7	0.8
CO_2 emissions (Mt)	17,808	20,479	23,113	32,353	34,696	35,373	35,133	1.8	0.5	0.1	0.2
GDP per capita ($2010 thousand)	6.3	7.2	8.2	10	14	17	20	1.4	2.0	1.8	1.9
Primary energy consump. per capita (toe)	1.6	1.7	1.6	1.9	1.9	1.9	1.9	0.4	0.2	0.0	0.0
Primary energy consumption per GDP[*2]	257	232	201	178	138	114	95	-1.0	-1.8	-1.9	-1.8
CO_2 emissions per GDP[*3]	634	541	463	418	298	231	183	-1.0	-2.4	-2.4	-2.4
CO_2 per primary energy consumption[*4]	2.5	2.3	2.3	2.4	2.2	2.0	1.9	0.0	-0.6	-0.6	-0.6

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

Table A56 | Asia [No New Coal-fired Power Plant (Renewables Substitution) Case]

Primary energy consumption

	Mtoe							Shares (%)			CAGR (%)			
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
Total[*1]	1,439	2,110	2,887	5,497	6,987	7,732	8,176	100	100	100	3.8	1.7	0.8	1.2
Coal	466	787	1,036	2,685	2,712	2,551	2,204	37	49	27	4.8	0.1	-1.0	-0.6
Oil	477	618	916	1,367	1,812	2,038	2,188	29	25	27	3.1	2.0	0.9	1.4
Natural gas	51	116	233	567	982	1,261	1,507	5.5	10	18	6.3	4.0	2.2	2.9
Nuclear	25	77	132	122	271	338	404	3.6	2.2	4.9	1.8	5.9	2.0	3.6
Hydro	20	32	41	138	182	205	221	1.5	2.5	2.7	5.8	2.0	1.0	1.4
Geothermal	2.6	8.2	23	40	93	119	144	0.4	0.7	1.8	6.3	6.3	2.2	3.9
Solar, wind, etc.	-	1.2	2.1	62	383	644	925	0.1	1.1	11	16.2	13.9	4.5	8.3
Biomass and waste	397	471	503	517	552	577	582	22	9.4	7.1	0.4	0.5	0.3	0.3

Final energy consumption

	Mtoe							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,129	1,556	1,991	3,709	4,774	5,398	5,863	100	100	100	3.4	1.8	1.0	1.4
Industry	383	514	647	1,511	1,789	1,959	2,086	33	41	36	4.2	1.2	0.8	1.0
Transport	124	184	318	661	969	1,120	1,226	12	18	21	5.1	2.8	1.2	1.8
Buildings, etc.	569	741	842	1,162	1,517	1,736	1,911	48	31	33	1.7	1.9	1.2	1.5
Non-energy use	54	117	185	375	499	583	640	7.5	10	11	4.6	2.1	1.3	1.6
Coal	301	424	373	899	915	922	899	27	24	15	2.9	0.1	-0.1	0.0
Oil	326	459	734	1,204	1,628	1,846	2,000	29	32	34	3.8	2.2	1.0	1.5
Natural gas	21	47	88	266	458	563	637	3.0	7.2	11	6.9	3.9	1.7	2.6
Electricity	88	156	278	784	1,214	1,506	1,781	10	21	30	6.4	3.2	1.9	2.4
Heat	7.5	14	30	96	110	117	119	0.9	2.6	2.0	7.6	1.0	0.4	0.6
Hydrogen	-	-	-	-	0.2	0.5	0.5	-	-	-	n.a.	n.a.	3.7	n.a.
Renewables	386	456	488	459	449	444	427	29	12	7.3	0.0	-0.2	-0.3	-0.2

Electricity generation

	(TWh)							Shares (%)			1990/	2016/	2030/	2016/
	1980	1990	2000	2016	2030	2040	2050	1990	2016	2050	2016	2030	2050	2050
Total	1,196	2,240	3,983	10,768	16,683	20,459	23,832	100	100	100	6.2	3.2	1.8	2.4
Coal	298	869	1,990	6,443	6,524	5,868	4,571	39	60	19	8.0	0.1	-1.8	-1.0
Oil	476	434	390	233	209	183	140	19	2.2	0.6	-2.4	-0.8	-2.0	-1.5
Natural gas	90	237	559	1,340	2,299	3,156	4,119	11	12	17	6.9	3.9	3.0	3.4
Nuclear	97	294	505	468	1,041	1,296	1,552	13	4.3	6.5	1.8	5.9	2.0	3.6
Hydro	232	369	478	1,603	2,118	2,382	2,565	16	15	11	5.8	2.0	1.0	1.4
Geothermal	3.0	8.4	20	24	60	77	94	0.4	0.2	0.4	4.2	6.7	2.2	4.1
Solar PV	-	0.1	0.6	152	1,888	3,492	5,201	-	1.4	22	34.4	19.7	5.2	10.9
Wind	-	-	2.4	294	2,172	3,516	4,988	-	2.7	21	41.7	15.4	4.2	8.7
CSP and marine	-	-	-	0.5	7.5	14	26	-	-	0.1	18.2	20.8	6.4	12.1
Biomass and waste	-	9.5	17	187	341	452	554	0.4	1.7	2.3	12.1	4.4	2.5	3.2
Hydrogen	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
Others	-	20	20	23	23	23	23	0.9	0.2	0.1	0.6	0.0	0.0	0.0

Energy and economic indicators

	1980	1990	2000	2016	2030	2040	2050	1990/ 2016	2016/ 2030	2030/ 2050	2016/ 2050
GDP ($2010 billion)	4,441	7,560	11,025	23,349	42,947	61,820	81,967	4.4	4.4	3.3	3.8
Population (million)	2,440	2,933	3,410	4,035	4,439	4,601	4,665	1.2	0.7	0.2	0.4
CO_2 emissions (Mt)	3,105	4,632	6,720	14,795	16,787	17,238	16,753	4.6	0.9	0.0	0.4
GDP per capita ($2010 thousand)	1.8	2.6	3.2	5.8	9.7	13	18	3.2	3.7	3.0	3.3
Primary energy consump. per capita (toe)	0.6	0.7	0.8	1.4	1.6	1.7	1.8	2.5	1.0	0.5	0.7
Primary energy consumption per GDP[*2]	324	279	262	235	163	125	100	-0.7	-2.6	-2.4	-2.5
CO_2 emissions per GDP[*3]	699	613	609	634	391	279	204	0.1	-3.4	-3.2	-3.3
CO_2 per primary energy consumption[*4]	2.2	2.2	2.3	2.7	2.4	2.2	2.0	0.8	-0.8	-0.8	-0.8

*1 Trade of electricity, heat and hydrogen are not shown, *2 toe/$2010 million,
*3 t/$2010 million, *4 t/toe

The 430th Forum on Research Work

IEEJ Outlook 2019

Energy transition and a thorny path for 3E challenges

Energy, Environment and Economy

Tokyo, 15 October 2018

The Institute of Energy Economics, Japan

Structure of IEEJ Outlook 2019

(1) Energy demand / supply and climate change up to 2050

Overviewing world energy market up to 2050 based on the "Reference Scenario" and the "Advanced Technologies Scenario"

Reference Scenario

Reflects past trends with the current energy and environment policies.
Does not reflect any aggressive policies for low-carbon measures.

Advanced Technologies Scenario

Assumes introduction of powerful policies to enhance energy security and address climate change issues.
The utmost penetration of low-carbon technologies is assumed.

(2) Risk and impact of energy supply disruptions

We discuss risks and measures for energy supply disruptions considering the characteristic of two energy sources; oil which has been at the heart of the traditional energy security debate and electricity which is expected to increase the role of energy supply in the future.

(3) No New Coal-fired Power Plant Case

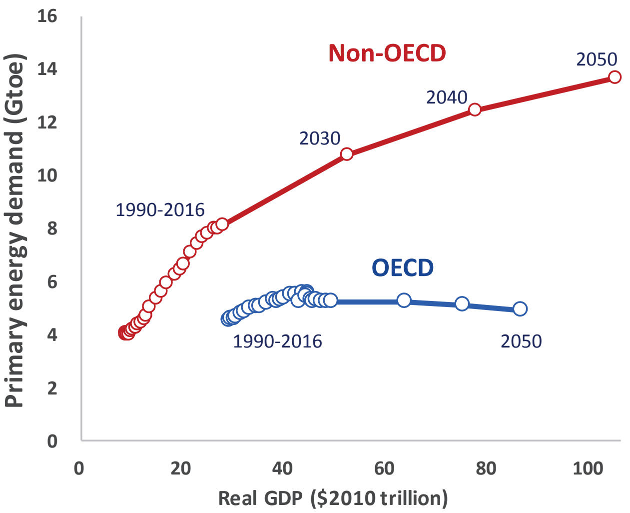
We simulated a hypothetical case in which all new coal-fired power plants would be banned from construction after 2020 without exception assuming two patterns for the substitution; a) natural gas-fired power generation, b) solar PV / wind power generation.

Energy supply / demand and climate change up to 2050

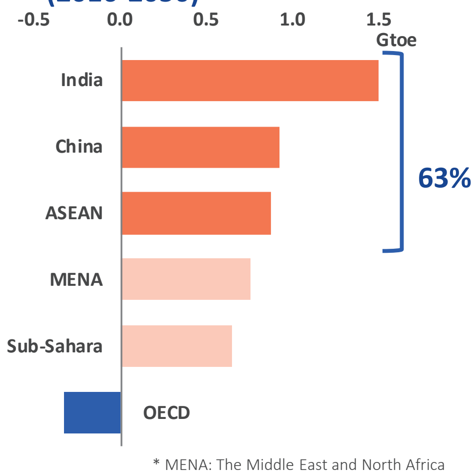
Reference Scenario

Dramatic growth of energy demand in Asia

Primary energy demand vs. real GDP



Change in energy demand (2016-2050)



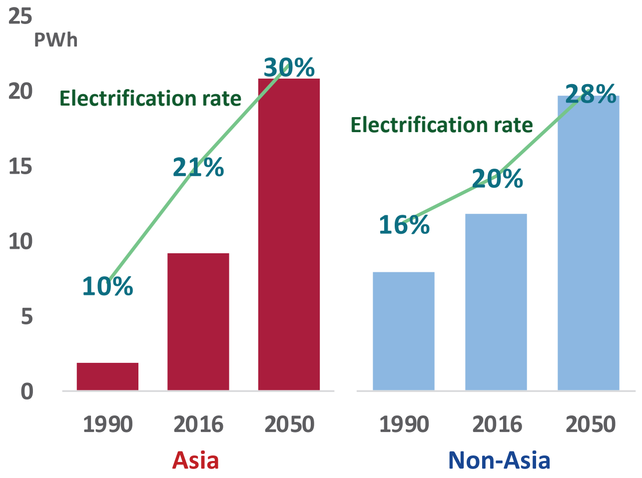
* MENA: The Middle East and North Africa

- The global primary energy demand will increase by 1.4 times in 2050.
- The net increase in energy demand can be entirely attributable to non-OECD.
- In OECD, decoupling between growth of the GDP and energy consumption proceeds.
- 63% of the increment come from China, India and the ASEAN countries.
- Share of Asia in the global primary energy demand will increase from 41% to 48%.

Reference Scenario

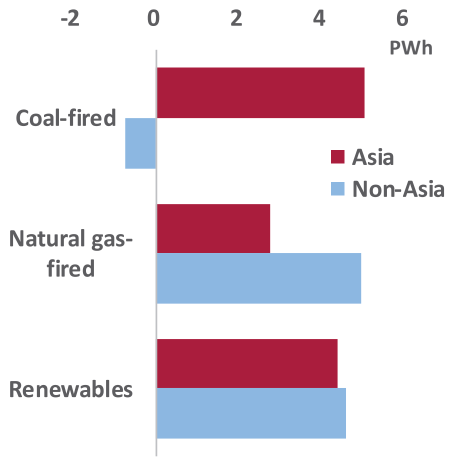
Growth of dependence to electricity

Electricity demand and electrification rate



* Electrification rate: Share of electricity in the final energy consumption

Change in electricity generation (2016-2050)

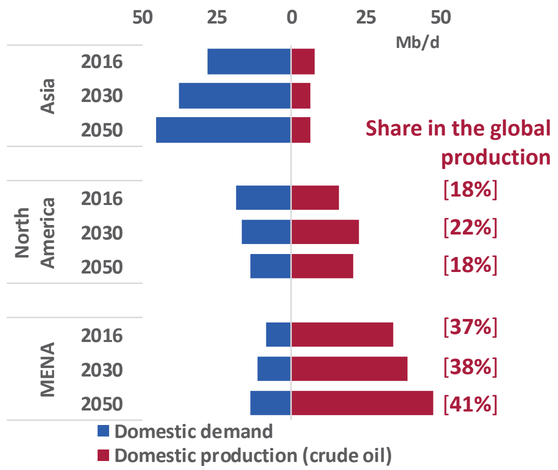


- 60% of the increment in the primary energy demand will be consumed for power generation.
- The global electricity demand will double in 2050, and 60% of the increment will occur in Asia.
- In Asia, electrification rate will increase to 30% in 2050, and 40% of electricity demand will be covered by coal, which can be obtained plentifully and inexpensively.
- Except for Asia, natural gas-fired power generation will be applied more than the coal-fired.

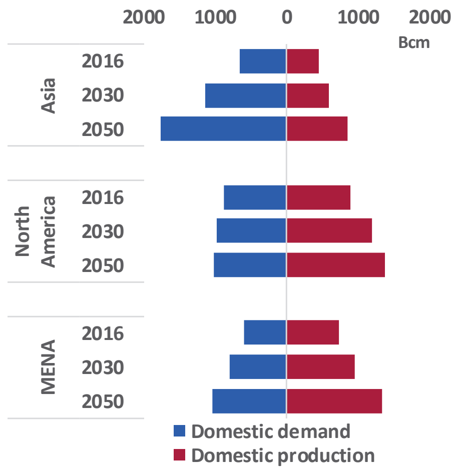
Reference Scenario

Expanding gap between supply and demand in Asia

Oil supply / demand



Natural gas supply / demand



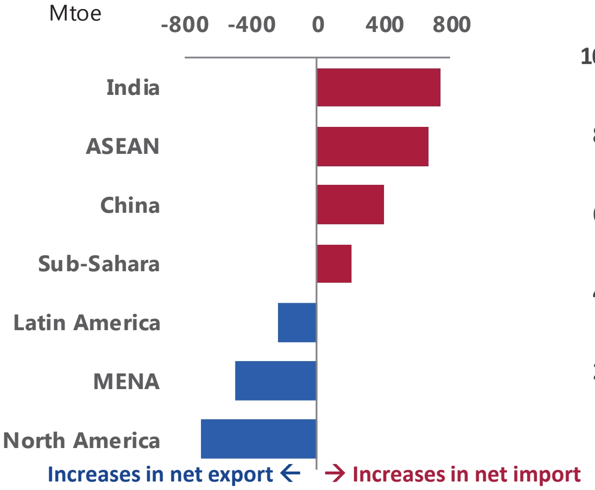
* North America: Canada and United States. MENA: The Middle East and North Africa

- In Asia, supply and demand gap is concerned, as demand for oil and natural gas increases more remarkably than their production.
- The gap will be covered by export from North America and MENA .
- Dependence on the Middle East will increase due to decrease of production of North America after 2030 (the OPEC share in oil production will increase from 42% to 47%).

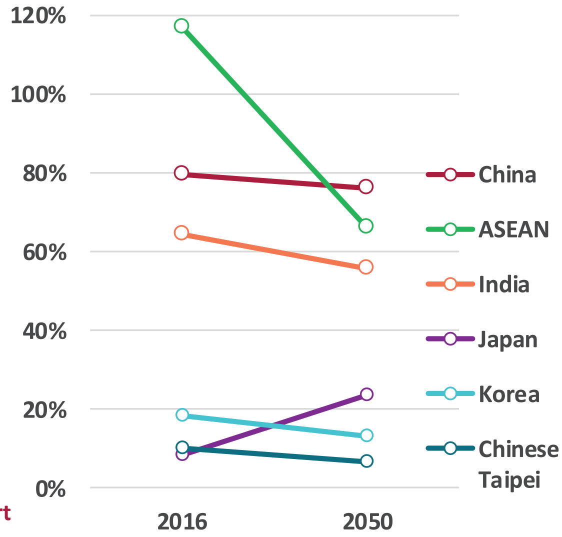
Reference Scenario

Increase of energy imports in Asia

Increase of net import energy (2016-2050)



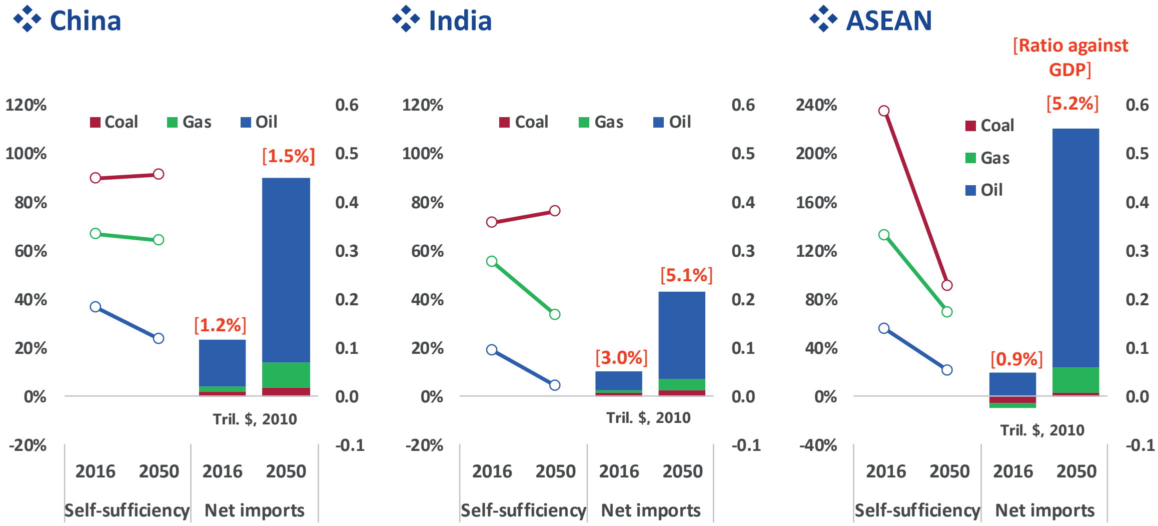
Self-sufficiency rate



- Energy imports of Asia will increase dramatically.
- 80% of energy traded globally will be consumed in Asia.
- United States will be a net exporter in the middle of the 2020s.
- Self-sufficiency rate in Asia will decrease from 72% to 63%. This tendency is remarkable for ASEAN, which will be a net importer in the first half of the 2020s.

Reference Scenario

Increase of oil import spending in Asia



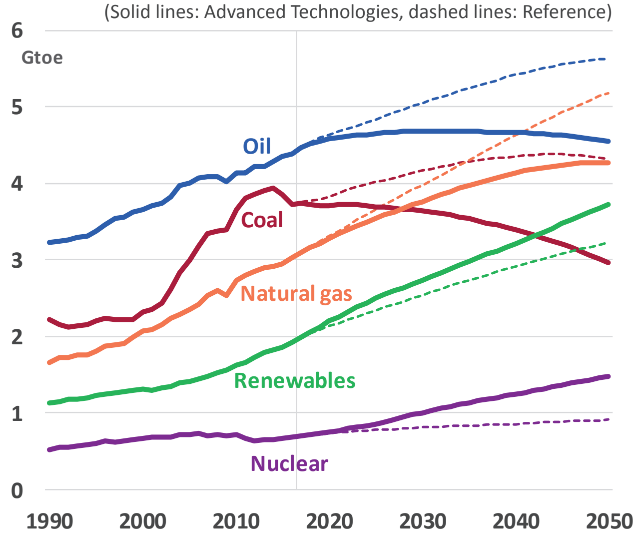
In Asia…

- Self-sufficiency rate of oil will decrease from 28% to 14%, due to increase of consumption for transportation. Self-sufficiency rate of natural gas will also decrease remarkably.
- Self-sufficiency rate of coal will be maintained at a level of 80%.
- The amount of oil import will increase remarkably, and the total amount of energy import will grow from 1.6% to 3.0% against the GDP (from 0.9% to 5.2% in the ASEAN).

Coal declines while oil hits peak in 2030

Primary energy demand

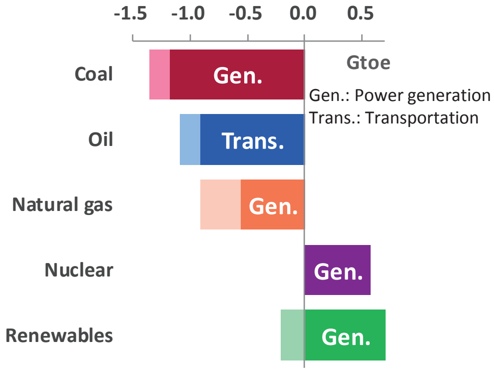
(Solid lines: Advanced Technologies, dashed lines: Reference)



Advanced Technologies Scenario

It is assuming preparation and implementation of more ambitious strategies or programs for energy security, mitigation of climate change and so on.

Comparison with the Reference

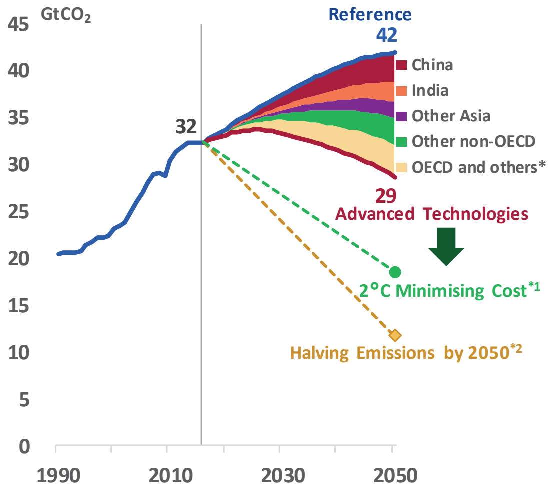


In the Advanced Technologies Scenario…

- Coal consumption will decrease remarkably (especially, for power generation).
- Oil consumption will decrease after peaking in 2030.
- Although share of fossil fuel in energy consumption will decrease from 81% to 69% in 2050 (to 79% in the Reference Scenario), high dependency on fossil fuel continues.

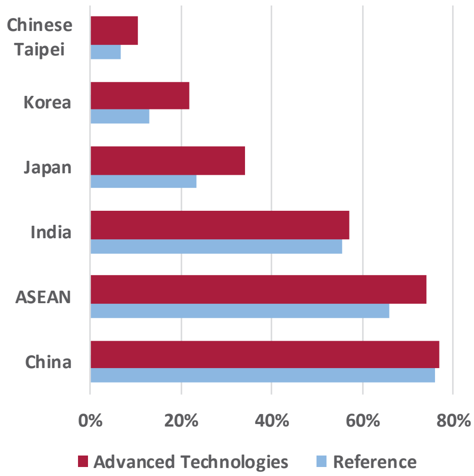
Improve environmental and security issues

Energy-related CO_2 emissions



* Includes international bunkers.
*1 Refer "IEEJ Outlook 2018". *2 This path represents an emission path in the RCP2.6 scenario summarised in the fifth Assessment Report by IPCC.

Self-sufficiency rate in Asia (2050)

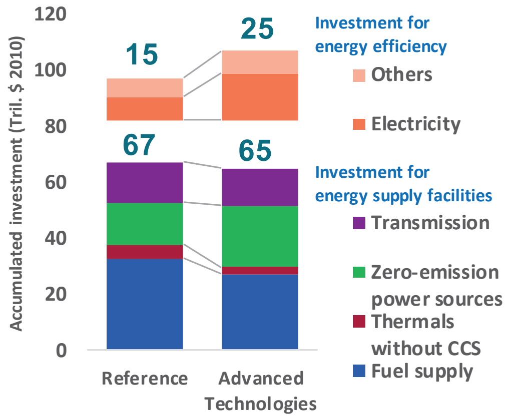


In the Advanced Technologies Scenario…

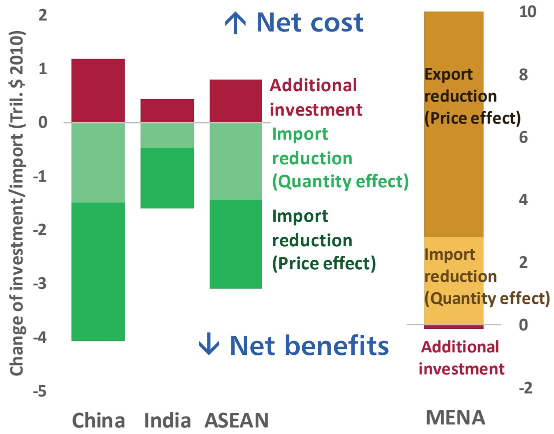
- CO_2 emissions will peak in the mid-2020s and will decrease by 11% in 2050 from 2016. However, to maintain temperature rise caused by the climate change within 2 degree Celsius, additional programs and innovative technologies are required.
- Compared with the Reference Scenario, self-sufficiency rate in Asia will improve by 3%p in 2050.

Required investment for energy supply

Required investment (2017-2050)



Difference of benefits and cost between two scenarios (2017-2050)



* "Electricity" includes the saving through electrification.

* MENA: The Middle East and North Africa

- In the Reference Scenario, $67 billion of investment is required for the energy supply facilities (1.5% against GDP).
- In the Advanced Technologies Scenario, $8 billion of investment is additionally required.
- In Asia, additional investment can be covered by the savings through reduction of fuel imports.
- In the Middle East, decreases in revenues from oil and natural gas export will be much more than decreases in the upstream investment.

Addressing climate change issues

――Republication of IEEJ Outlook 2018――

Rule for ultra long-term: Reduce the total cost

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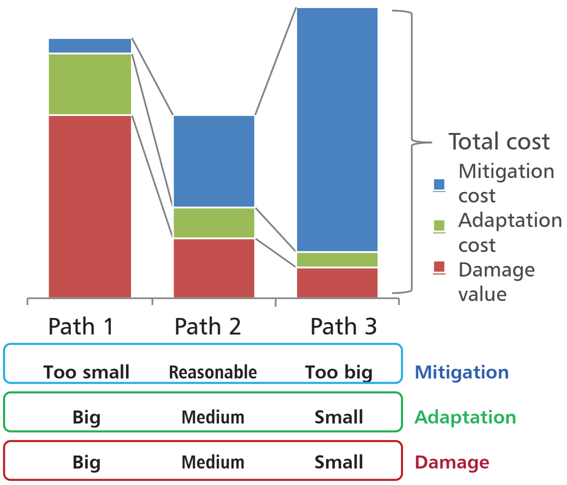
❖ Mitigation + Adaptation + Damage = Total cost

Mitigation	Typical measures are GHG emissions reduction via energy efficiency and non-fossil energy use. Includes reduction of GHG release to the atmosphere via CCS These measures **mitigate** climate change.
Adaptation	Temperature rise may cause sea-level rise, agricultural crop drought, disease pandemic, etc. **Adaptation** includes counter measures such as building banks/reservoir, agricultural research and disease preventive actions.
Damage	If mitigation and adaptation cannot reduce the climate change effects enough to stop sea-level rise, draught and pandemics, **damage** will take place.

❖ Illustration of total cost for each path



Without measures against climate change, the mitigation cost is small, while the adaptation and damage costs become substantial. Aggressive mitigation measures on the other hand, would reduce the adaptation and damage costs but the mitigation costs would be notably colossal.
The climate change issue is a long-term challenge influencing vast activities over many generations. As such, and from a sustainability point of view, the combination (or the mix) of different approaches to reduce the total cost of mitigation, adaptation and damage is important.

Minimising total cost in IAM*

* Integrated Assessment Model

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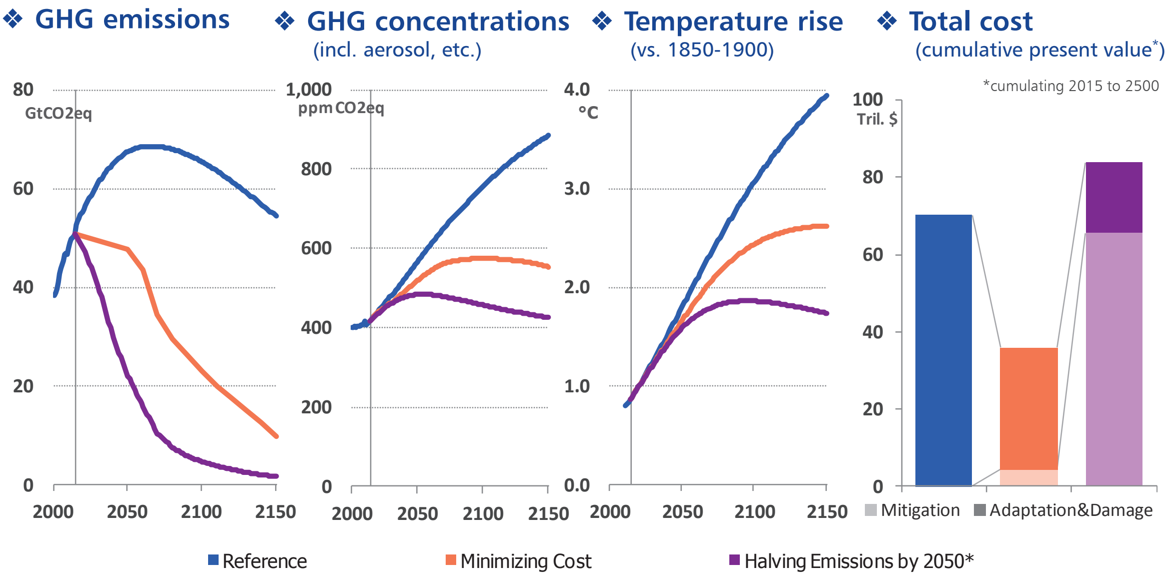

Total cost of the Minimising Cost Path is half of the Reference Path. In 2150, GHG emissions decrease by 80% from now and temperature rises by 2.6 °centigrade from the late 19th century. In the Halving Emissions by 2050 Path, temperature peaks at 2100, resulting in 1.7°C in 2150. However, total cost is 20% higher than the Reference Path and double of the Minimising Cost Path.

* Emissions path reflected “RCP 2.6” in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

Still large uncertainties in the climate analysis

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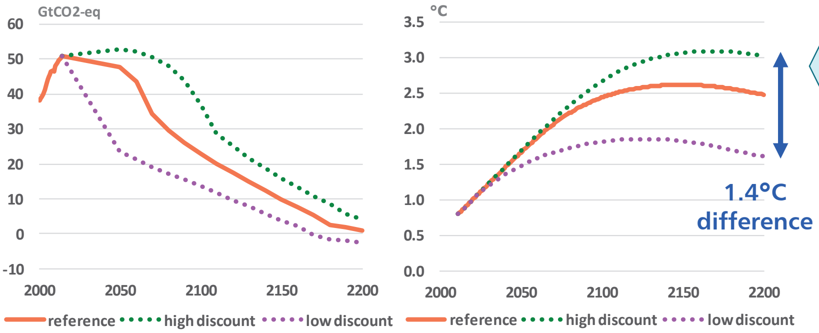
❖ GHG emissions and temperature rise using different discount rates (Minimising Cost)



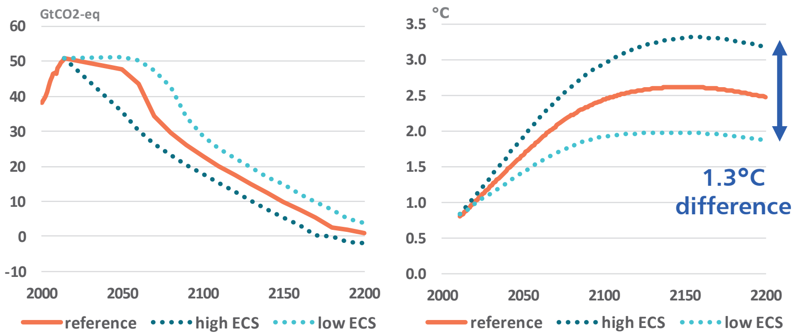
Discount rate
This model uses 2.5%. There are a range of 1.1 to 4.1% summarised by AR5.

Note: The value used when converting future value (income and expenditure) into the current value. The lower discount rate tends to raise emphasis of adaptation and damage, and strengthen immediate GHG reduction. The higher discount rate raises emphasis of mitigation costs and delays GHG reduction efforts.
Although the rate changes every year in the model analysis, it is represented by the average value in 2015 to 2300 here.

❖ GHG emissions and temperature rise using different ECS (minimising cost)

Equilibrium Climate Sensitivity (ECS)
This model uses 3 degree. According to AR5, high possibility that ECS is between 1.9 and 4.5 degree.

Note: A parameter indicating how much degrees centigrade the temperature will rise when the atmospheric greenhouse gas concentration (CO_2 equivalent concentration) doubles.



Another path to "2°C target"

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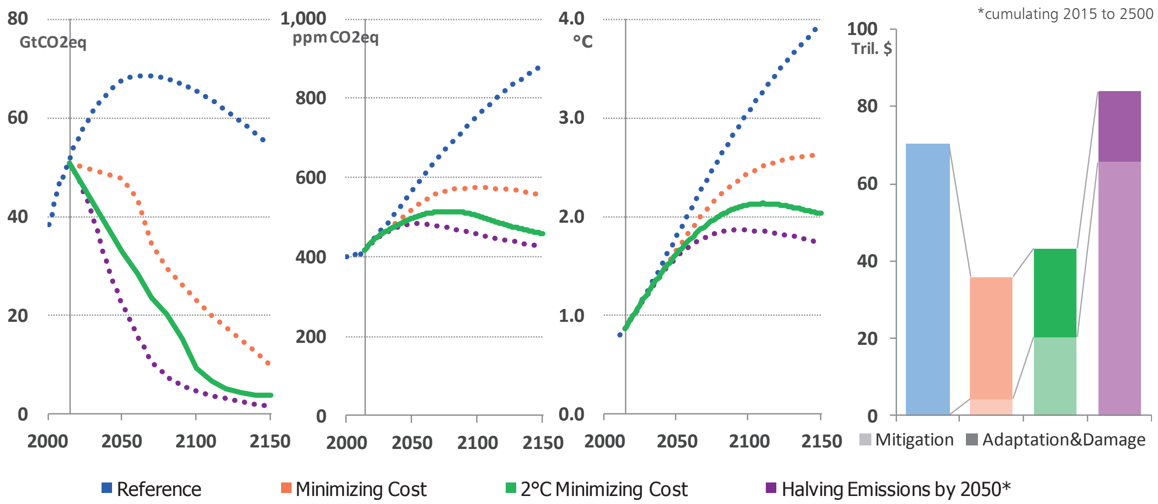
❖ GHG emissions ❖ GHG concentrations (incl. aerosol, etc.) ❖ Temperature rise (vs. 1850-1900) ❖ Total cost (cumulative present value*)



"2°C Minimising Cost Path," for example, is a path that minimise total cost under the condition of 2°C temperature rise in 2150. Its total cost is 20% higher than the Minimising Cost Path without the temperature limit. GHG emissions decrease by 30% in 2050 and needs almost zero-emissions after 2100. Temperature rises to just over 2°C in 2100 and then declines to 2°C.

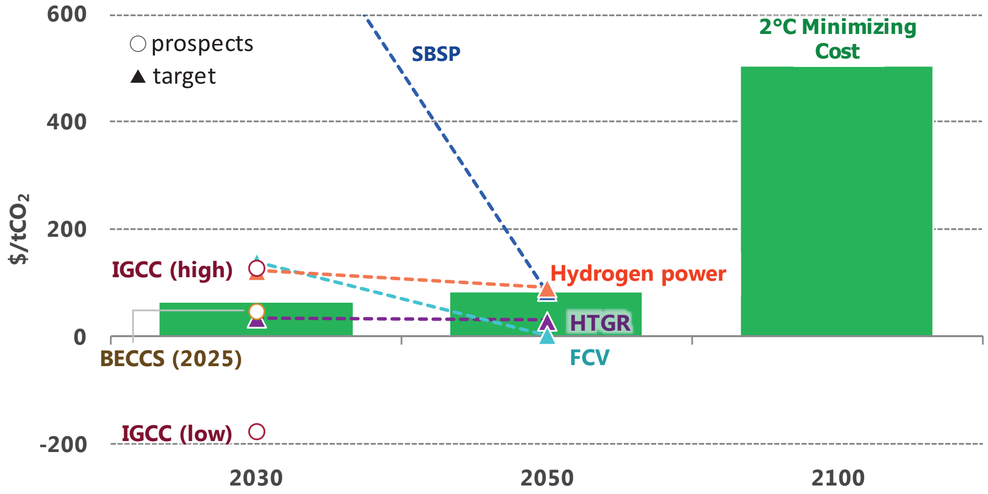
* Emissions path reflected "RCP 2.6" in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

Technology development for ultra long-term

Technologies		Description	Challenges
Technologies to reduce CO_2 emissions	Next generation nuclear reactors	Fourth-generation nuclear reactors such as ultra-high-temperature gas-cooled reactors (HTGR) and fast reactors, and small- and medium-sized reactors are now being developed internationally.	Expansion of R&D support for next generation reactors
	Nuclear fusion reactor	Technology to extract energy just like the sun by nuclear fusion of small mass number such as hydrogen. Deuterium as fuel exists abundantly and universally. Spent nuclear fuel as high-level radioactive waste is not produced.	Technologies for continuously nuclear fusion and confining them in a certain space, energy balance, cost reduction, financing for large-scale development and establishment of international cooperation system, etc.
	Space-based solar power (SBSP)	Technologies for solar PV power generation in space where sunlight rings abundantly above than on the ground and transmitting generated electricity to the earth wirelessly via microwave, etc.	Establishment of wireless energy transfer technology, reduction of cost of carrying construction materials to space, etc.
Technologies to sequestrate CO_2 or to remove CO_2 from the atmosphere	Hydrogen production and usage	Production of carbon-free hydrogen by steam reforming of fossil fuels and by CCS implementation of CO_2 generated.	Cost reduction of hydrogen production, efficiency improvement, infrastructure development, etc.
	CO_2 sequestration and usage (CCU)	Produce carbon compounds to be chemical raw materials, etc. using CO_2 as feedstocks by electrochemical method, photochemical method, biochemical method, or thermochemical method. CO_2 can be removed from the atmosphere.	Dramatic improvement in quantity and efficiency, etc.
	Bio-energy with carbon capture and storage (BECCS)	Absorption of carbon from the atmosphere by photosynthesis with biological process and CCS.	It requires large-scale land and may affect land area available for the production of food, etc.

Lower cost is key for innovative technologies

❖ CO_2 reduction cost by innovative technology



Note: Cost (= carbon price) for "2°C Minimising Cost" is the highest cost of the technology adopted at each year. Refer to IEEJ Outlook 2018 for detail.

Implicit carbon price for the 2°C Minimising Cost Path is $85/tCO$_2$ in 2050. The target costs for innovative technologies, such as BECCS, hydrogen-fired power generation, FCV, HTGR, and SBSP are within the range of the carbon price. The 2°C target can be reached with using these technologies. It is important to enhance R&D from the long-term view and international collaboration is dispensable.

Further CO_2 reductions from Advanced Technologies Scenario

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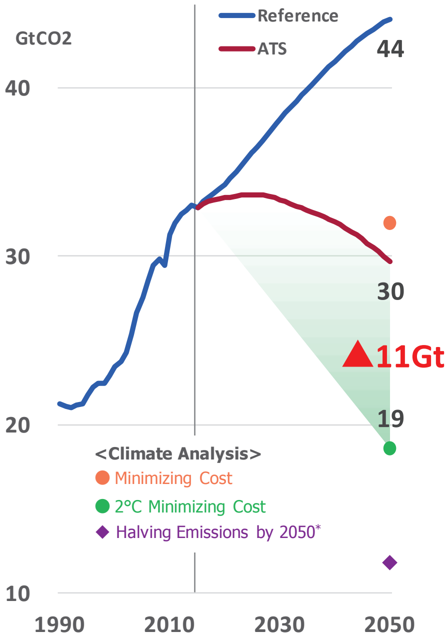
❖ Energy-related CO_2 emissions



❖ Examples of technologies for further reductions

1) CO_2-free hydrogen (refer to Asia/World Energy Outlook 2016)
- **Hydrogen-fired power generation: 1 GW x 3,000 units**
- **Fuel cell vehicles: 1 billion units**

(H_2 demand of 800 Mt/yr corresponds 3 times of today's LNG)

2) Negative-emission technology
- **BECCS (Biomass-fired power generation): 0.5 GW x 2,800 units**

(Fuel supply of 2,000 Mtoe/yr needs land of 2.85 million km²)

3) Zero-emission power generation and factories with CCS

-10 $GtCO_2$ (Maximum reduction volume by substituting for thermal power generation without CCS)

- **SPS: 1.3 GW x 2,300 units**

or • **HTGR: 0.275 GW x 8,700 units**

or • **Nuclear fusion reactor: 0.5 GW x 4,500 units**

or • **Thermal power generation with CCS: 2,800 GW**

(Estimated CO_2 storage potential is over 7,000 Gt)

+

-1 $GtCO_2$
- **CCS: Installed in 20% of factories and plants**

(iron & steel, cement, chemicals, pulp & paper, refinery and GTL/CTL)

* Emissions path reflected "RCP 2.6" in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

IEE JAPAN

Risk and impact of energy supply disruptions

Causes of oil supply disruptions

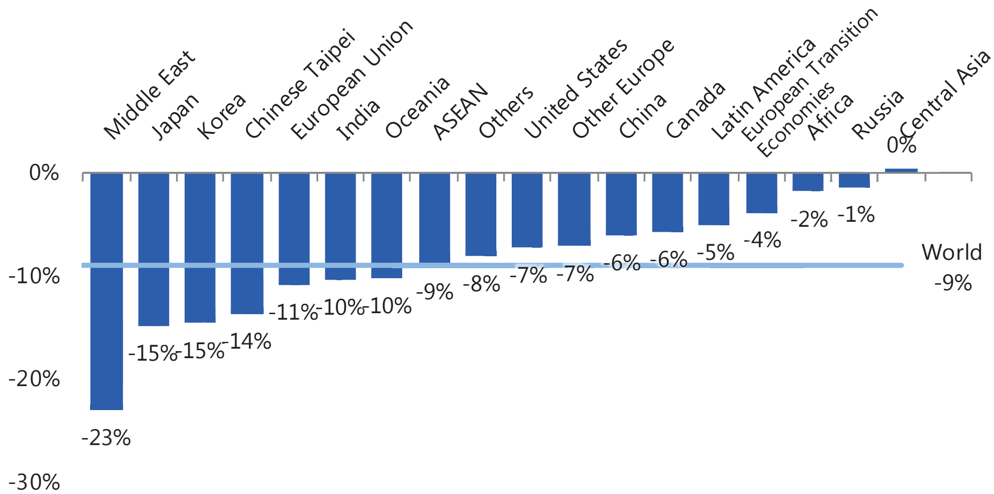
- Oil supply disruptions have been at the heart of the traditional energy security debate.
- Various supply disruptions have occurred at each stage of production, transport, and domestic supply due to accidents, failures, natural disasters, or structural factors affecting society and the economy as a whole. And the risks remain present.

	Risks	Examples
Production	• Destruction or shutdown of production facilities due to unanticipated events such as accidents, failures or natural disasters • Destruction of production facilities and suspension of operations due to political upheavals and terrorism • Halting exports by political will or strategy	1973: OAPEC countries imposed an embargo on exports to the United States and the Netherlands. 2005: Hurricanes shut down oil production facilities in the U.S. Gulf Coast 2018: Exports of crude oil from Libya were partially reduced because of suspension of production and the blockade of ports due to internal strife.
Transportation	• Destruction or shutdown of facilities due to unanticipated events such as accidents, failures or natural disasters • Destruction or suspension of transportation (ships, pipelines, etc.) by terrorism or piracy • Interruption of transport routes by political will, strategy and military action	1984 - 1988: The "tanker war" by Iran and Iraq 2011: Destruction of gas pipelines from Egypt to Israel by terrorist attacks 2018: Attacks on crude oil tankers by Yemeni militants
Domestic Supply	• Destruction or shutdown of supply facilities due to unpredictable events such as accidents, failures or natural disasters • Destruction of supply facilities and suspension of operations due to terrorism	2011: Oil supply suspension due to the damage of oil refineries and oil depots and the destruction of ports, railways and roads caused by the Great East Japan Earthquake

Impacts of the disruption of oil supply on economy

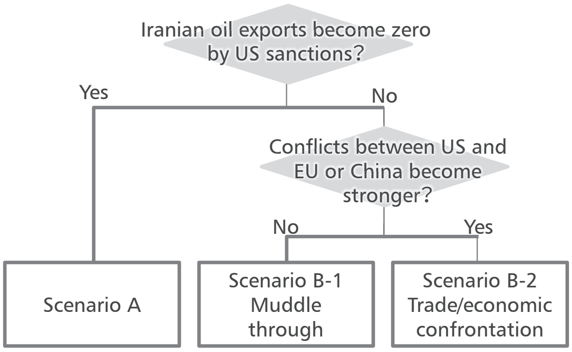
- The disruption of oil supply has major impacts.
- If crude oil production in the Middle East falls by 10 Mb/d and other countries or regions cannot fill in the gap, the global economy would shrink by 9%.
- Except for the Middle East, the epicentre of supply disruptions, Japan, Korea and Chinese Taipei would suffer the most damage.

❖ Impact of a 10 Mb/d decline in crude oil production in the Middle East on real GDP



Impacts of sanctions against Iran on international oil market

- Key result of scenario analysis on the impacts, up around 2020, of US re-imposition of economic sanctions against Iran.
- In the scenario where Iranian crude oil exports (about 2.5 Mb/d) are totally eliminated, oil prices rise due to shortage of OPEC spare capacity.
- In the scenario where trade friction starting from US escalates, world's economic slowdown relaxes oil supply-demand, and eventually pushes down oil prices.



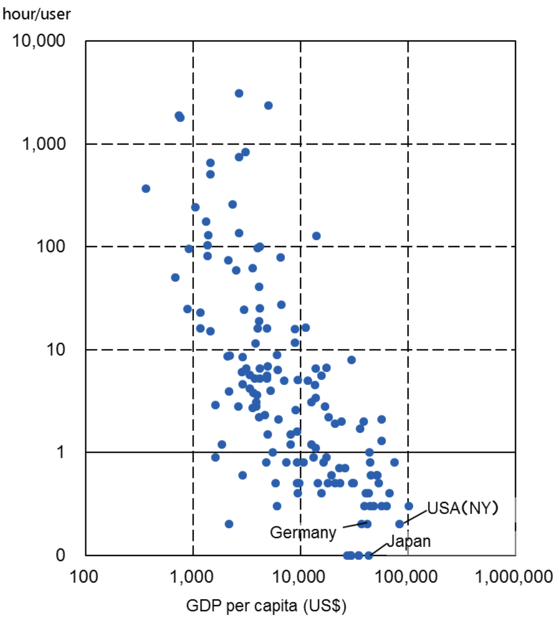
❖ Points of the scenario analysis

	Scenario A	B-1	B-2
Oil market	Tight supply-demand balance and shortage of OPEC spare capacity	Relatively calm market condition thanks to production increase from Saudi Arabia, etc.	Oversupply due to economic slowdown
Oil price	80-100$/bbl or more depending on circumstances	70-80$/bbl	50$/bbl
Other energy	LNG demand decline with the rise of prices. Coal becomes more competitive.	-	Lower LNG price materialise potential demand. FIDs of new liquefaction plans are postponed.

Source: IEEJ, Scenario analysis on the impacts of sanctions against Iran on international oil market, August 2018

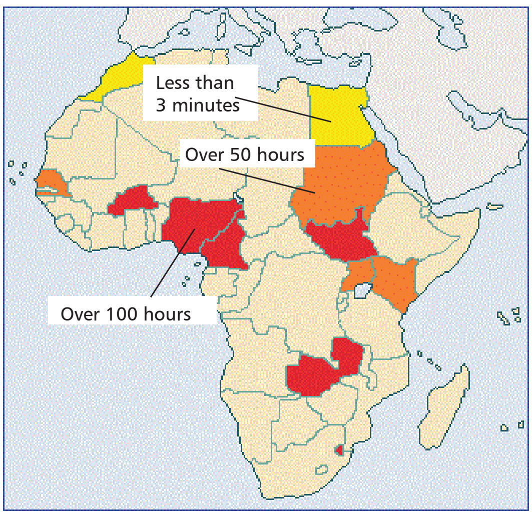
International comparison of power outage

❖ Income level and power outages (2015)



Source: World Bank "Doing Business database", "World Bank Open Data"

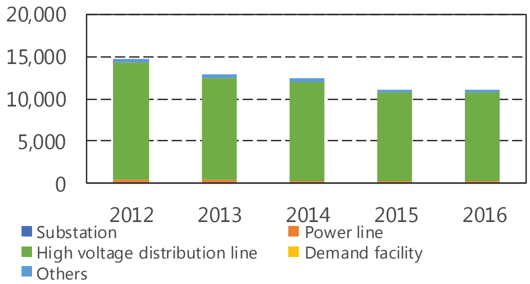
- Power outages vary widely by region. Sub-Saharan, island states, and South Asia tend to be long.
- The countries where power outages exceeded 1,000 hours (11% per year) in 2015 are Iraq, Comoros, Eritrea, Nigeria, Pakistan, South Sudan, and Swaziland.



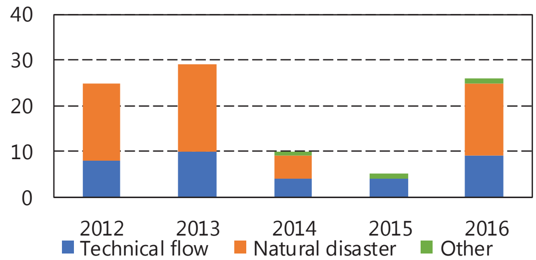
Power outage in Japan

- More than ten thousand power outage has occurred in Japan if including low voltage. The main cause is a distribution system and the extent of the suffered area is limited in the most power outage.
- Large scale power outage sometime increases due to natural disaster (typhoon, heavy rain, etc.).
- In the developed countries, the grid modernisation including automation of transmission and distribution system enables the swift recovery if there is no physical damage.

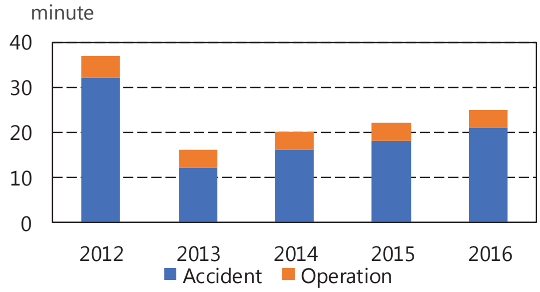
❖ Number of power outage by cause



❖ Number of large-scale power outage



❖ Power outages per low voltage user



Source: Organization for Cross-regional Coordination of Transmission Operators, Japan "Reports about the quality of electricity", Nov. 2017.

New threat for power supply

Structural risk

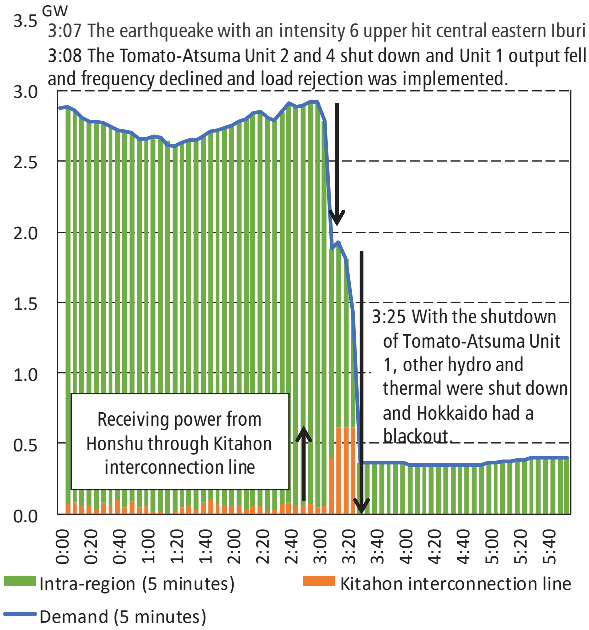
- **The increasing dependence on a specific energy source**
  ✓ While regions which depend on gas-fired power generation have increased in the United States and natural gas is supplied by pipeline, the supply risk caused by natural gas supply disruption becomes more evident.
- **The "duck curve" of net load due to the expansion of solar PV**
  ✓ In California and Japan where introduction of solar PV power generation is expanding, the duck curve of net load which the peak load comes twice a day is progressing. Requirement for electricity supply capacity is increasing that can follow, particularly, steep rise of electricity demand from daytime to early evening.
- **The shutdown of power plants due to economic feasibility**
  ✓ There is a risk of unexpected large-scale closure of power generation capacity in the short term due to its economic feasibility. In the United States, during 2012 to 2017, large capacities (coal-fired: 55 GW, gas-fired: 36 GW, nuclear: 5 GW) were closed due to unfavourable market condition. Unbundled power business structure is challenging the transmission system operator or the reliability assessment organisation to capture such plans.

Sudden risk

- **Cyber attacks**
  ✓ In Ukraine, power outage occurred due to cyber attacks in December 2015 and December 2016. Power system control was hacked and ended up power outage. When capacity of virtual power plants (VPPs), connecting distributed power generators via open network, increases in the future, cyber attacks can possibly risk VPP system.

The massive blackout following the 2018 Hokkaido Eastern Iburi earthquake

❖ Background of the blackout in Hokkaido



Source: Hokkaido Electric Power "Electricity forecast", Organization for Cross-regional Coordination of Transmission Operators, Japan. "System information service", JEPX "Electric information public system"

Background of the blackout

3:07 The earthquake with an intensity 6 upper hit central eastern Iburi.

3:08 Supply -1.8 GW, demand -1.4 GW

	GW
Tomato-Atsuma Unit 2 and 4 shut down	-1.16
Tomato-Atsuma Unit 1 output fall	-0.05
Hydro stopped due to an accident in the transmission line	-0.43
Wind stopped due to low frequency	-0.17
Blackout due to an accident in the transmission line	-0.13
Automatic load shedding with low frequency	-1.3

3:09 The frequency recovered after received electricity from Kitahon interconnection (0.5 GW).

3:20 The frequency dropped again due to output fall of Tomato-Atsuma Unit 1. Hokkaido area became blackout due to run-out of margin to maintain frequency.

The cause of the blackout

The shutdown of power generation capacity larger than the mandate obligation of primary reserve (3% of the demand of relevant time: about 0.09 GW)

The recovery from the blackout

13:35 Sunagawa thermal unit 3 restarted by using power supply from hydroelectric.

Sep 8 2:00 The recovery rate was 99%.

Feature of oil and electricity in supply disruption

	Oil	Electricity
Geographical spread of the impacts	**Wider** • The impact of a crisis in an oil producing country or international transportation route spreads to the world. • Soaring international oil price spreads to every corner of the world economy within a short period of time.	**Limited** • The most of an impact is limited to the country or region
Demand substitutability	**More elastic** • Substitutable in some usage such as boiler and power generation	**Less elastic** • No substitutability in most usages
Response to supply disruptions	• Diversification of import partner countries / routes • Geographical distribution of domestic facilities • Redundancy of domestic supply network • Support for economic stabilisation in oil-producing countries • Stockpiling	• Diversification of power generation fuels • Geographical distribution of power generation facilities • Redundancy of transmission and distribution networks • Reserve power generation capacity

Note: Evaluation on geographical spread and demand substitution show relative relation between oil and electricity.

Preparation for emergency

Oil

- Stockpiles is developed in many countries on their own way and amount.
- Among the IEA member countries, collaborative response mechanism is established.
- Within Japan, collaboration system among oil companies and central service station (SS) / inhabitants SS are being established.
- Japan which has no choice but to depend imports will remain exposed to the supply disruption.

↓

- **Maintenance and enhancement of security system is required.**

Electricity

- Before the deregulation of electricity market, the big electric utilities ensured backup power capacity voluntarily more than regulatory requirement.
- In the deregulated market, it becomes impossible to depend on the voluntary effort of the big electric utilities.
- On the other hand, technological innovations enable applying new measures.
  - More accurate supply-demand projection using AI
  - Managing demand using IoT
  - Adjusting supply-demand using storage battery in EVs

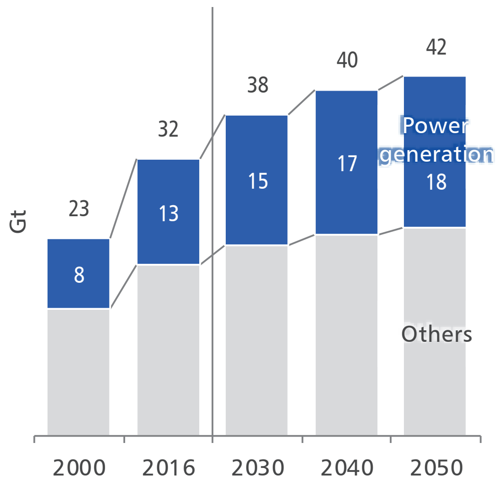
↓

- **Establishing appropriate security systems in the electricity market is desired.**

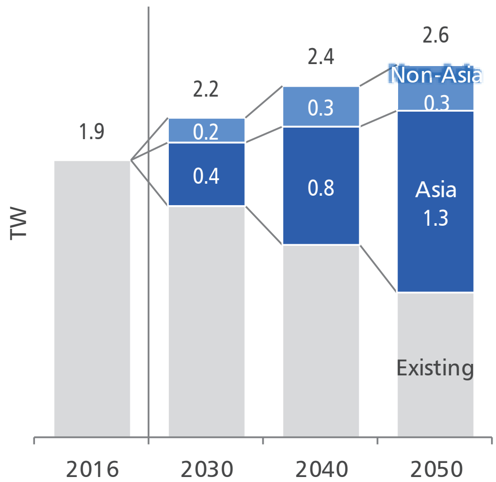
Impact of banning construction of new coal-fired power plants

Decarbonisation in power sector is required

❖ CO_2 direct emissions [Reference Scenario]



❖ New coal-fired power plant capacity [Reference Scenario]



Of additional emissions in 2050 (9.6 Gt), more than half (5.2 Gt) comes from power sector.

ESGs and divestment movements discourage investment for coal-fired power plant.

In the Reference Scenario, coal keeps the largest share in power generation mix.

In 2050, 1.6 TW of new coal-fired power plants were built after 2020 exist. → Without them?

No New Coal-fired Power Plant Case

—— a hypothetical option in the future

There are a lot of problems to be worked on to accomplish the shift from coal.

However, such problems in the real world are set aside in this case study.

No New Coal-fired Power Plant Case

A hypothetical case in which all new coal-fired power plant construction would be banned after 2020.

Two patterns with different substitution options (natural gas; solar PV / wind) for coal-fired power generation are prepared:

No New Coal-fired Power Plant (Natural Gas Substitution) Case

No New Coal-fired Power Plant (Renewables Substitution) Case

Judging from base-load function of coal-fired power generation, nuclear can be supposed as one of the substitution options. However, world-wide nuclear penetration requires challenges on technology transfer, matured regulation, and non-proliferation, which are difficult to overcome in short period. In addition, today's coal phase-out opinions rarely suppose the substitution of nuclear. Therefore, just two patterns (natural gas and renewables) are prepared in this case study.

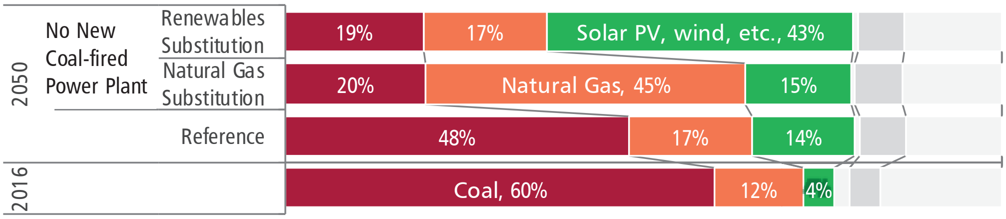
Discuss effects of banning the construction of new coal-fired power plants, in terms of energy supply-demand balances and economics.

⚠ No New Coal-fired Power Plant Case does not indicate prospect or feasibility of the coal-fired power plant ban.

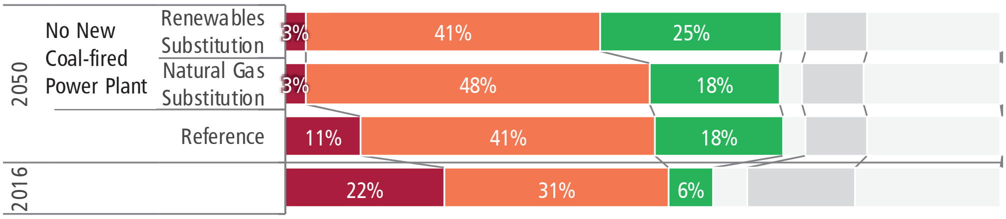
Drastic transition of power generation mix! Especially in Asia!!

❖ Power generation mix

Asia



Non-Asia

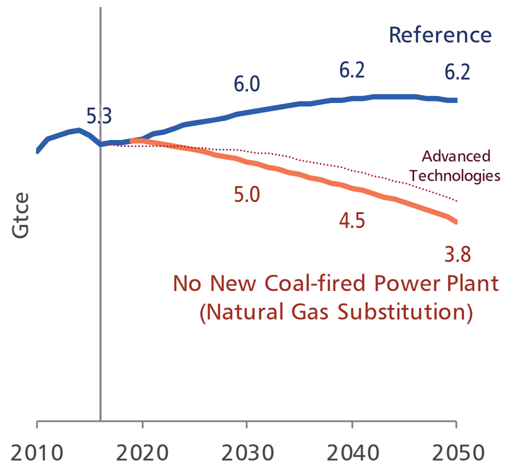


Since Asia largely depends on coal-fired power generation, abolishment of coal-fired power plant construction means drastic transition of power generation mix.

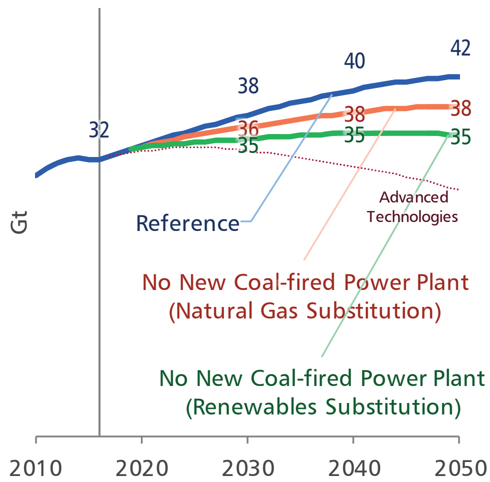
On the other hand, transition is relatively limited in non-Asia. Even if solar PV and wind substitute for coal-fired power generation, natural gas remains the largest share.

Pros of ban on new coal-fired power plant construction

❖ Primary consumption of coal



❖ CO_2 emissions



The reduction of 2.3 Gtce in 2050 is comparable to the current production of China.

It leads to reduction of local pollutants.

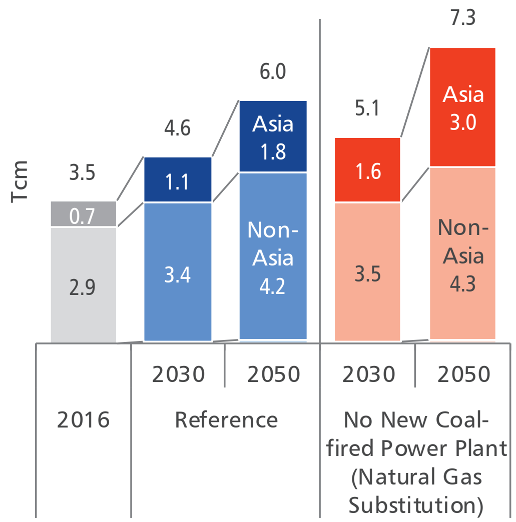
CO_2 reduction in 2050 is 3 Gt (Natural Gas Substitution), or 7 Gt (Renewables Substitution).

However, even in the latter case, CO_2 emissions are not less than the current level.

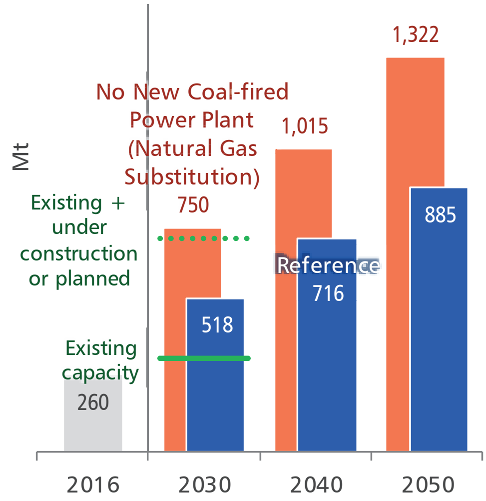
Note: Consumption of coal in the Renewables Substitution is almost same as that of the Natural Gas Substitution.

Substitution of natural gas requires dramatic expansion of supply

❖ Natural gas supply



❖ LNG demand



Natural gas consumption in 2050 reaches twice the current level. Cumulative consumption until 2050 may exceed the proven reserves.

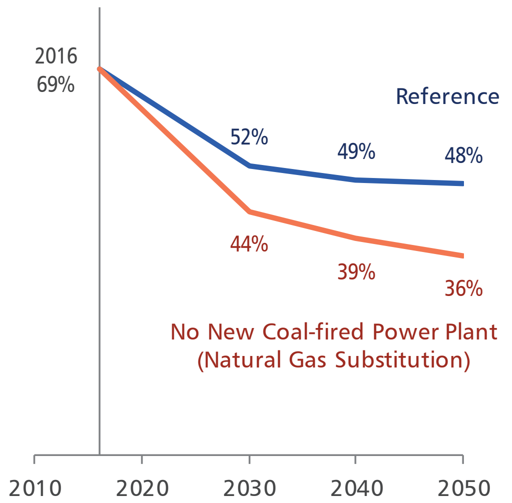
All possible resources need to be developed no matter how difficult.

LNG demand in 2030 is 3 times the current level.

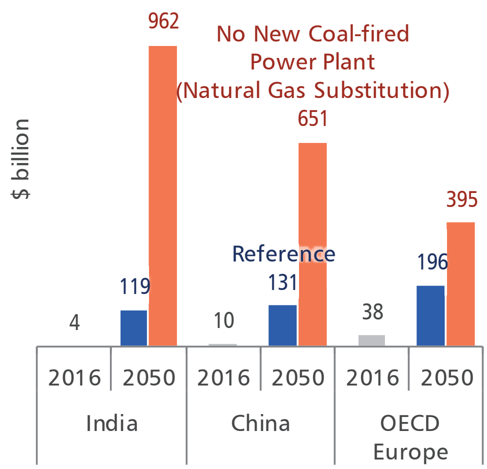
To meet enormous demand, even LNG projects without definite developed plan need to come into operation.

Challenges are not only the supply chains…

❖ Natural gas self-sufficiency rate (Asia)



❖ Net import spending of natural gas



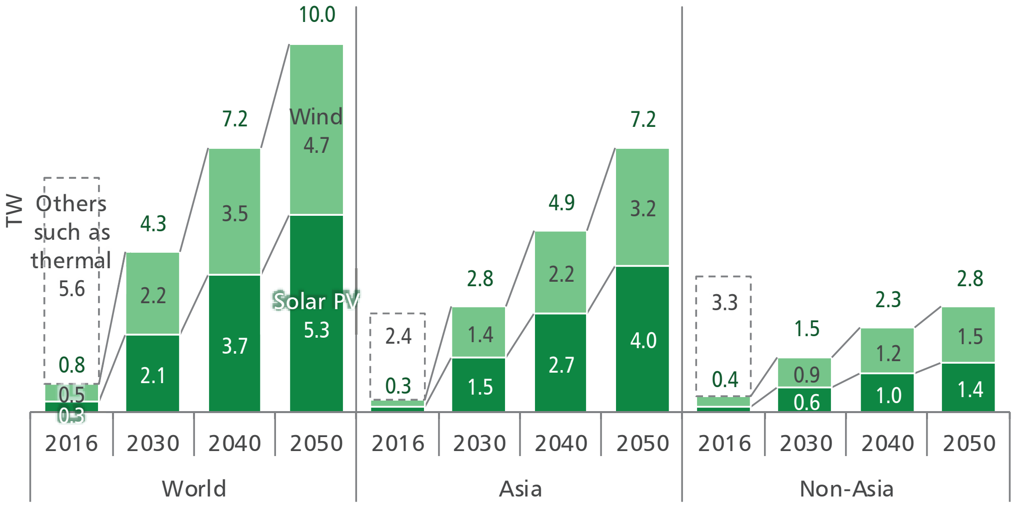
Even if these rapid increases in production and trade can be realised, Asia will face energy security problems.

Self-sufficiency rates of natural gas fall to half of the current level.

If natural gas prices rise due to drastic increase of demand, undesired effects reach non-Asia such as OECD Europe, in which natural gas demand slightly increases.

Substitution of solar PV / wind requires unprecedented capacity expansion

❖ Solar PV and wind power generation capacity
[No New Coal-fired Power Plant (Renewables Substitution) Case]

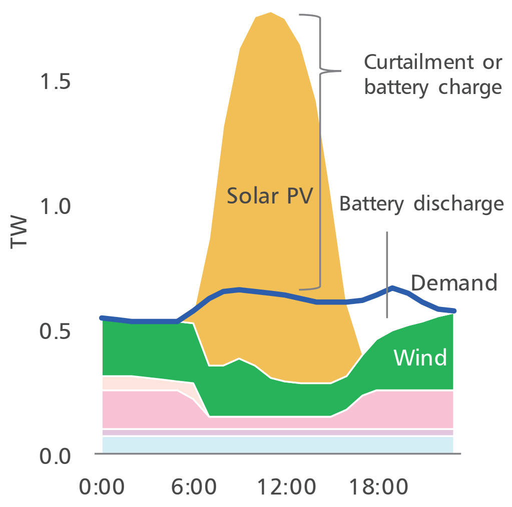


Even if efficient storage and transmission technologies without any loss become available worldwide, 10 TW of solar PV and wind power generation capacity combined is required in 2050.

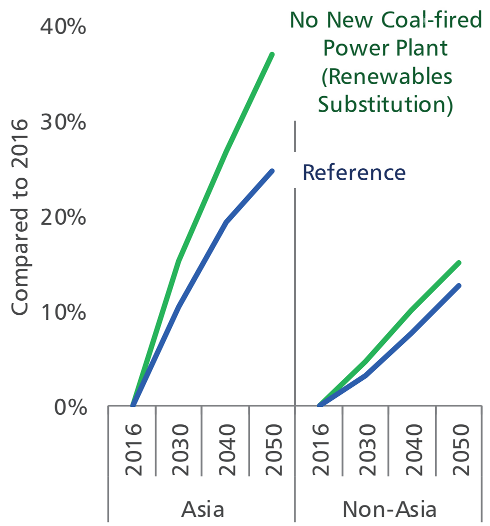
In Asia, solar PV and wind power generation capacity combined reaches 7.2 TW, 2.7 times the current total generation capacity. Sustainable measures to promote mass adoption are essential.

Keep an eye on electricity security

❖ Electricity balance in India «indicative»
[No New Coal-fired Power Plant (Renewables Substitution) Case, 2050]



❖ Electricity cost «indicative»



Electricity supply and demand must always be balanced.

Urgent subjects are technical study on frequency, voltage, transient stability, etc. under massive introduction of variable power sources.

It is necessary to make preparation, such as facility implementation and operation alteration for massive introduction of variable renewables.

In Asia, despite cost increase, avoid energy poverty and a decline in competitiveness.

Note: Shape of demand load curve is based on the current curve.

Note: does not include levies for renewable power source promotion.

Victoria concordia crescit
(Victory comes from harmony)

An entire ban on construction of coal-fired power plants

☺ 3 Gt～7 Gt of CO_2 reduction

☹ Drastic increase of alternative energy demand

Energy security challenges such as natural gas / electricity stable supply, economics, etc.

!

The country should promote to abolish coal-fired power generation that can do so.

If difficult, or with better CO_2 reduction measures, they should assess their priorities, making effort quickly to replace low-efficiency coal-fired power plants with high-efficiency ones and reduce dependency on coal-fired power generation.

Always keep in mind……

Are you prepared to support for the drastic energy transition in developing Asia?

Think it over.

Shift from coal-fired power generation is only one means, and that the end is to address climate change.

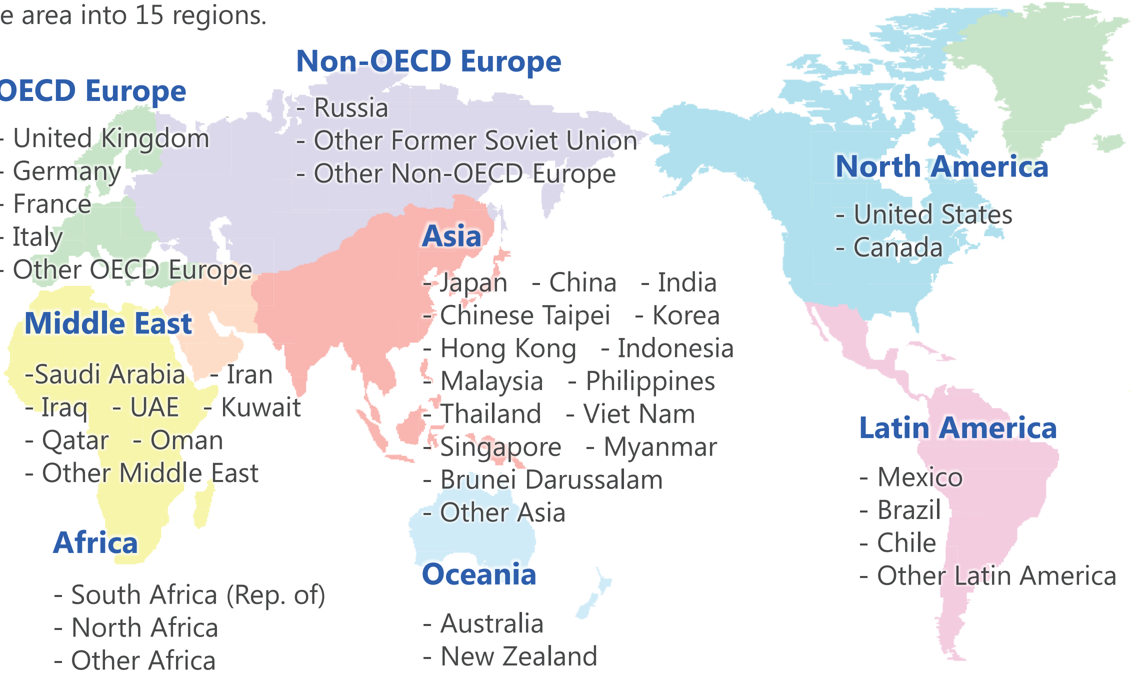
On a larger scale,

Climate change is one of humanity's great challenges, but not the only one.

Reference materials

Geographical coverage

Countries / regions in the world is geographically aggregated into 42 regions.
Especially the Asian energy supply / demand structure is considered in detail, aggregating the area into 15 regions.



OECD Europe
- United Kingdom
- Germany
- France
- Italy
- Other OECD Europe

Non-OECD Europe
- Russia
- Other Former Soviet Union
- Other Non-OECD Europe

North America
- United States
- Canada

Middle East
-Saudi Arabia - Iran
- Iraq - UAE - Kuwait
- Qatar - Oman
- Other Middle East

Asia
- Japan - China - India
- Chinese Taipei - Korea
- Hong Kong - Indonesia
- Malaysia - Philippines
- Thailand - Viet Nam
- Singapore - Myanmar
- Brunei Darussalam
- Other Asia

Latin America
- Mexico
- Brazil
- Chile
- Other Latin America

Africa
- South Africa (Rep. of)
- North Africa
- Other Africa

Oceania
- Australia
- New Zealand

Modelling framework

Major assumptions
GDP, population, energy prices, exchange rates, international trade, etc.

Macroeconomic model
Calculate GDP-related indices, price indices, activity indices including material production, etc. consistently.

Technology assessment model
Use a bottom-up approach to calculate future efficiencies of appliances, vehicles, etc.

Optimal power generation planning model
Calculate the cost-optimal power generation mix to meet the projected future electricity demand.

Energy supply-demand model
Econometric model to project future energy supply and demand by regression analysis of historical trends based on the energy balance tables data of the International Energy Agency.
This model calculates energy demand, supply and transformation as well as related indices including CO_2 emissions, CO_2 intensities and energy self-sufficiency ratios.

Experts' opinions

World trade model
Use the linear programming (LP) method to calculate the future international trade flows of crude oil, petroleum products, etc.

Computable general equilibrium model
Estimate economic impacts induced by changes in energy supply and demand, based on input-output table data.

Climate change model
Calculate future GHG concentration in the atmosphere, temperature rise, damage caused by climate change, etc.

Scenarios and a case in IEEJ Outlook 2019

Reference Scenario

Reflects past trends with the current energy and environment policies.
Does not reflect any aggressive policies for low-carbon measures.

Advanced Technologies Scenario

Assumes introduction of powerful policies to enhance energy security and address climate change issues.
The utmost penetration of low-carbon technologies is promoted.

No New Coal-fired Power Plant Case

A hypothetical case in which all new coal-fired power plants would be banned from construction after 2020 substituted by natural gas-fired or solar PV / wind power generation

Examples for technology [2050]

			2016	Reference	Advanced Technologies	No New Coal-fired Power Plant[*1]
Energy efficiency	Efficient coal-fired power generation[*2]	2030		30%	70%	-
		2050		90%	100%	-
	ZEV[*3] sales share	2030		11%	20%	Same as Reference
		2050		26%	46%	
	Intensity in steel industry[*4]		286	240	215	
	Insulation in the household (vs. 2016)			Improve by 24.4%	By 27.4%	
Fitting CCS to coal- or natural gas-fired power generation[*5]				None	New plants after 2030	
Zero emission power sources	Nuclear (GW)		406	518	859	
	Solar PV		290	2,110	2,922	5,341
	Wind		465	2,254	3,351	4,671

*1 No New Coal-fired Power Plant (Renewables Substitution) Case *2 Share of ultra super critical, advanced-USC and integrated coal gasification combined cycle in newly built coal-fired power plant *3 ZEV: Battery electric vehicles, plug-in hybrid electric vehicles and fuel cell battery vehicles *4 Energy consumption per crude steel production (toe/kt)
*5 Only countries and regions with CO_2 storage potential excluding aquifers

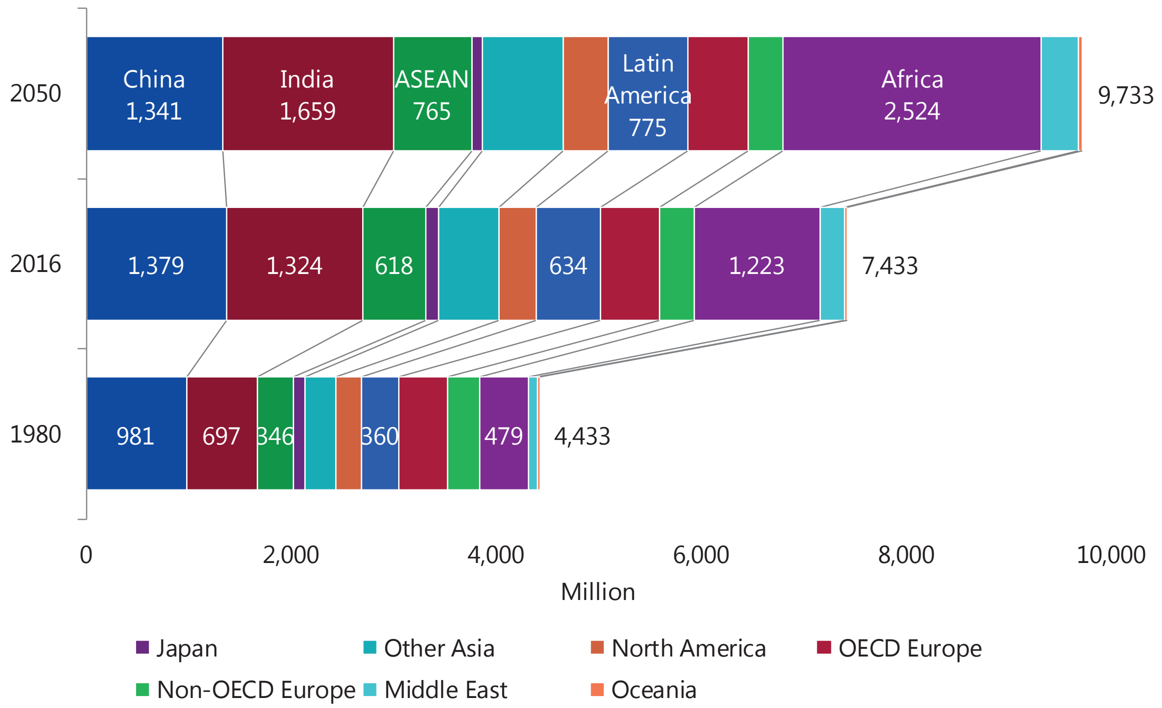
Climate Model Analysis

Reference Path
Emissions path with continuing past trends

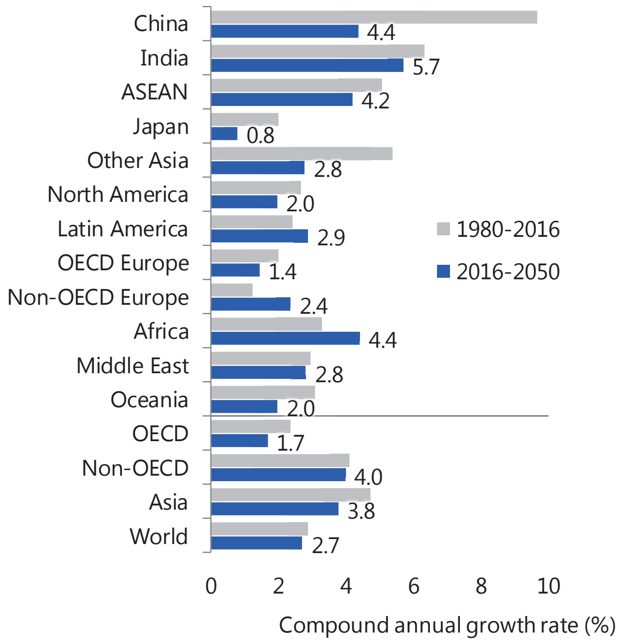
Minimising Cost Path
Emissions path with minimising total cost

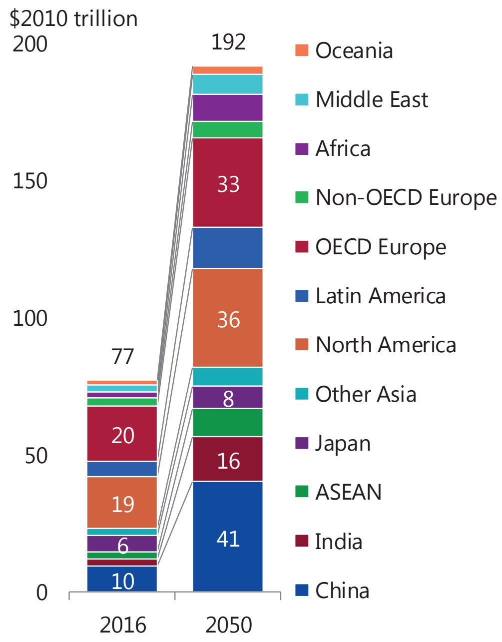
Halving Emissions by 2050 Path
Emissions path reflected RCP2.6 in AR5 by IPCC

Major assumption: Population



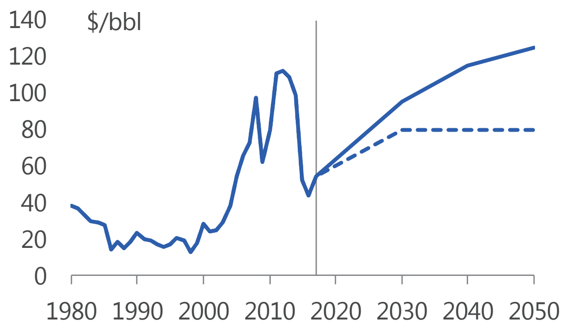
Major assumption: Real GDP



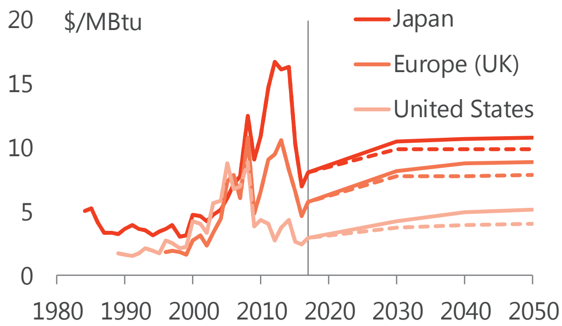


Major assumption: Intl. energy prices

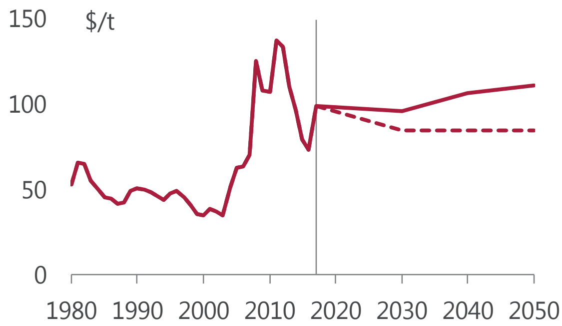
Crude oil



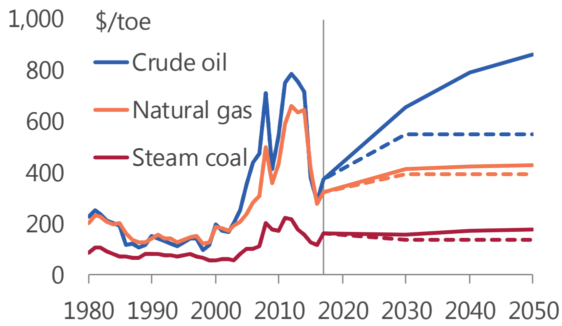
Natural gas



Steam coal



CIF import prices for Japan



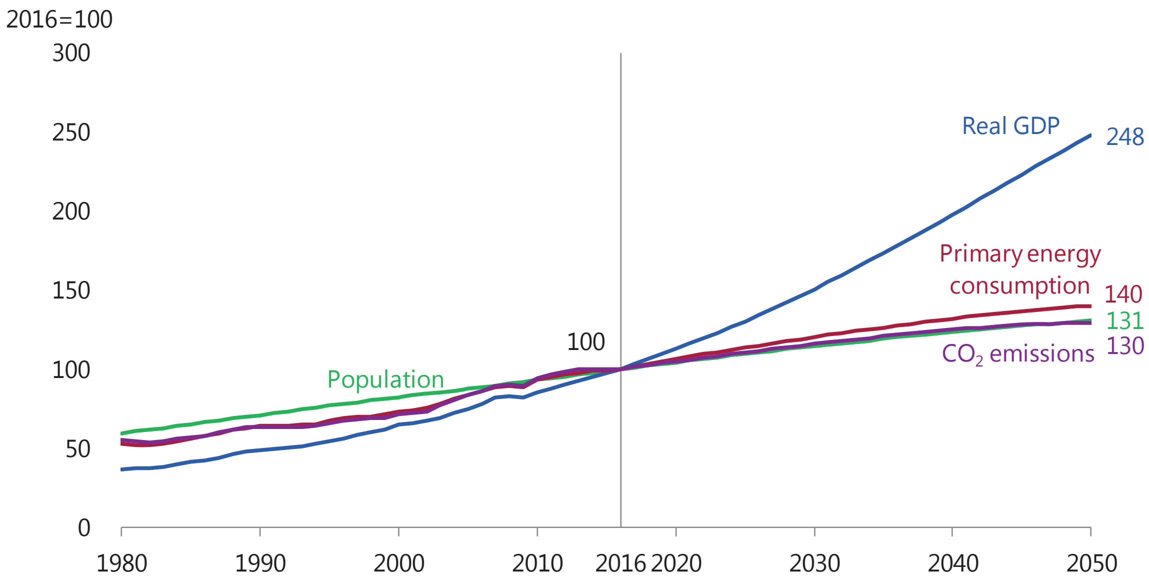
* Historical prices are nominal. Assumed future prices are real in $2017. Solid lines for the Reference Scenario and dotted lines for the Advanced Technologies Scenario.

Energy outlook in the world and Asia, 2016 - 2050

Reference Scenario

Reference Scenario

World population, GDP, energy and CO_2

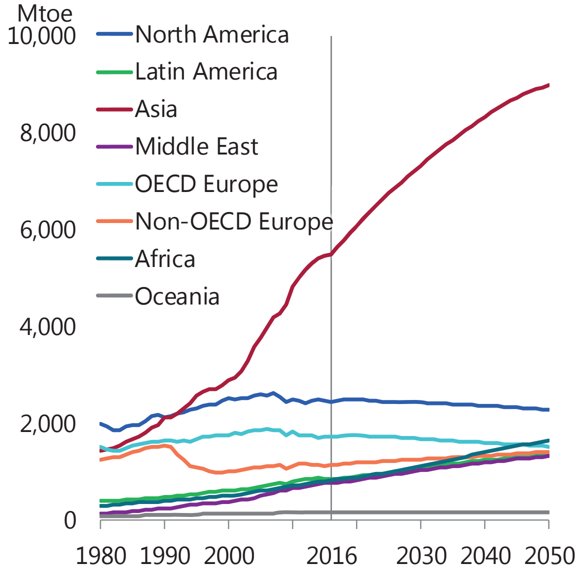


Reference Scenario

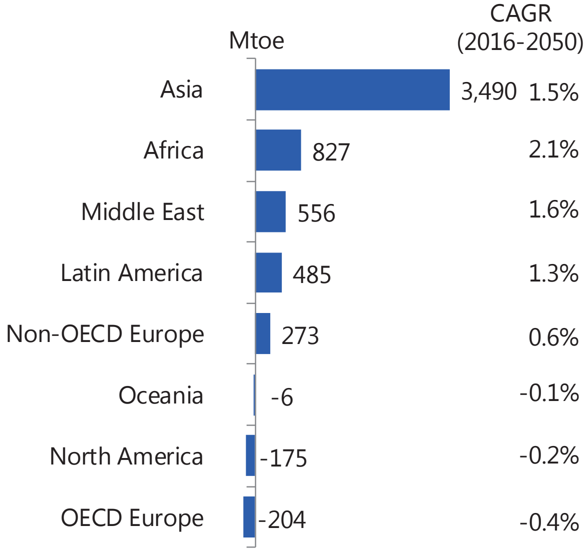
Primary energy consumption (by region)

World

2016	→	2050
13.8 Gtoe	(1.4 times)	**19.3** Gtoe



Changes (2016-2050)

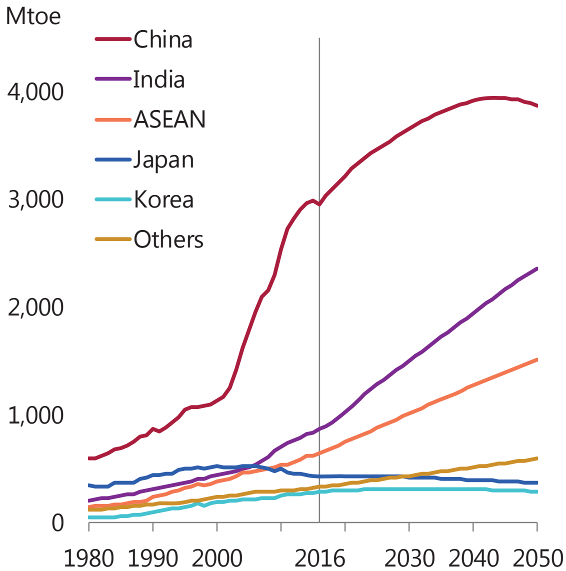


Reference Scenario

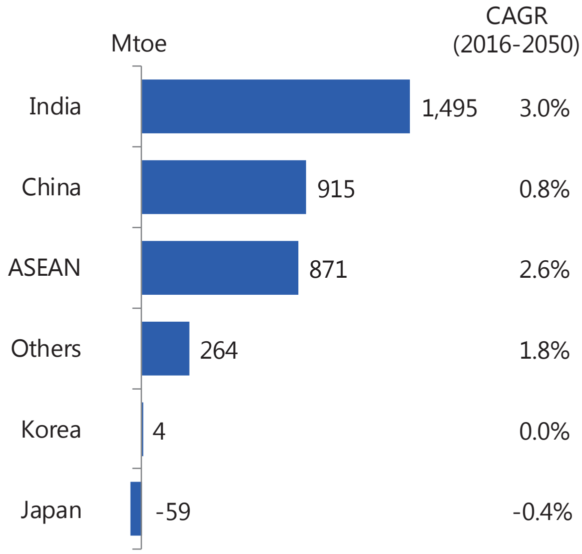
Primary energy consumption (Asia, by region)

Asia

2016	→	2050
5.5 Gtoe	(1.6 times)	**9.0** Gtoe



Changes (2016-2050)

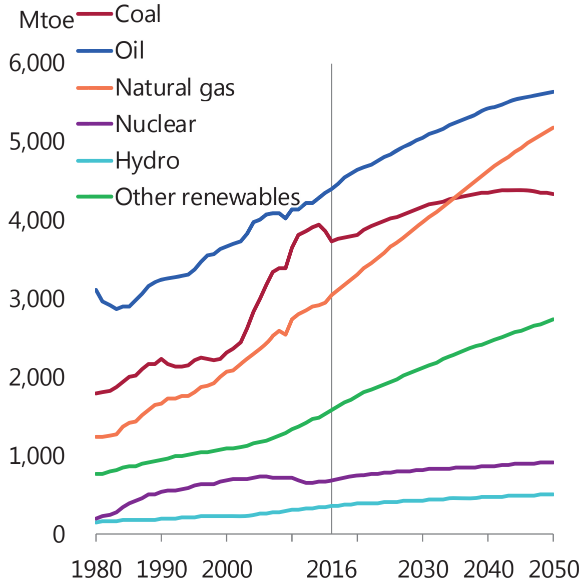


Reference Scenario

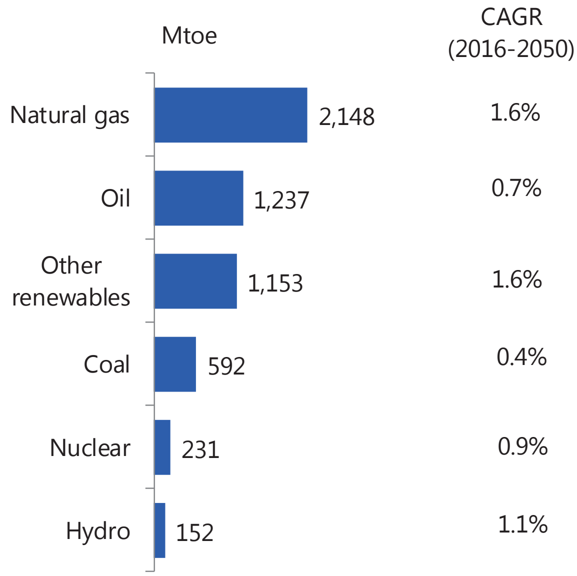
Primary energy consumption (by source)

World

2016	→	2050
13.8 Gtoe	(1.4 times)	**19.3** Gtoe



Changes (2016-2050)

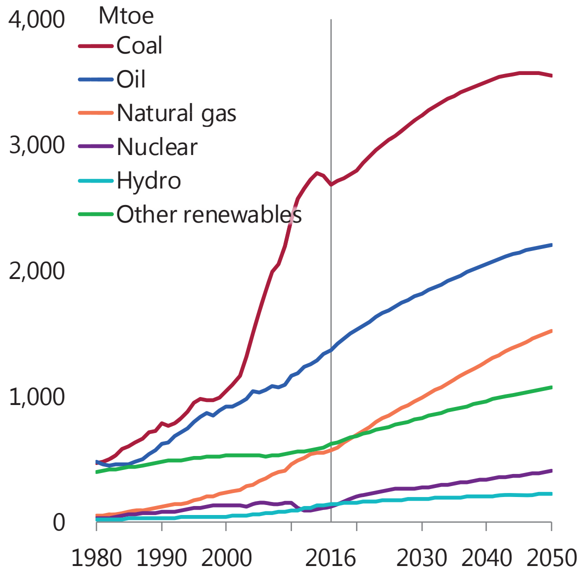


Reference Scenario

Primary energy consumption (Asia, by source)

Asia

2016	→	2050
5.5 Gtoe	(1.6 times)	**9.0** Gtoe



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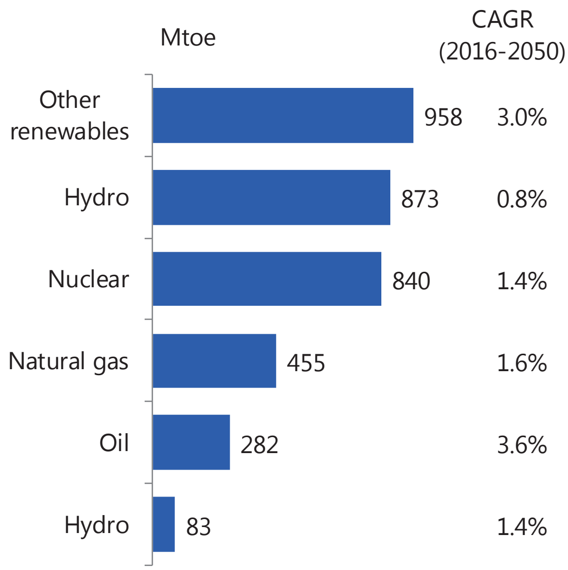
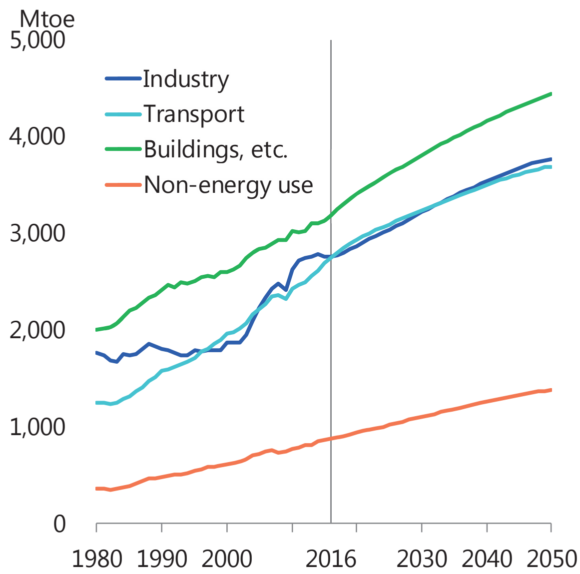


Reference Scenario

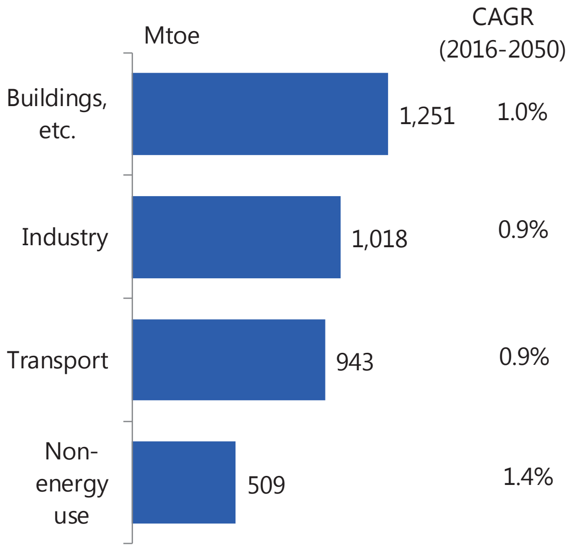
Final energy consumption (by sector)

World

2016	→	2050
9.6 Gtoe	(1.4 times)	**13.3** Gtoe



Changes (2016-2050)

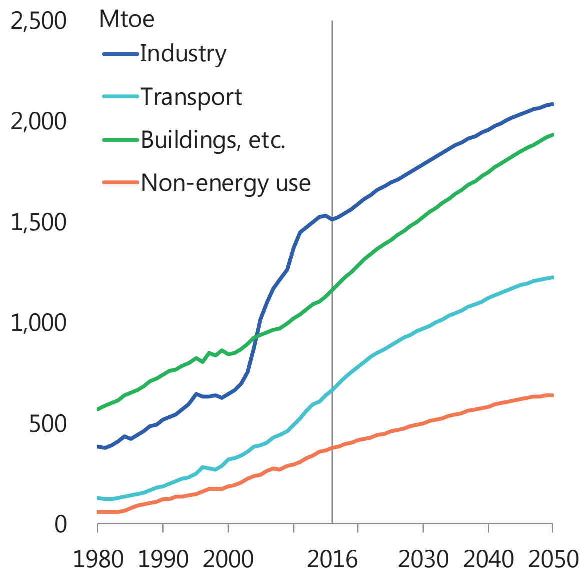


Reference Scenario

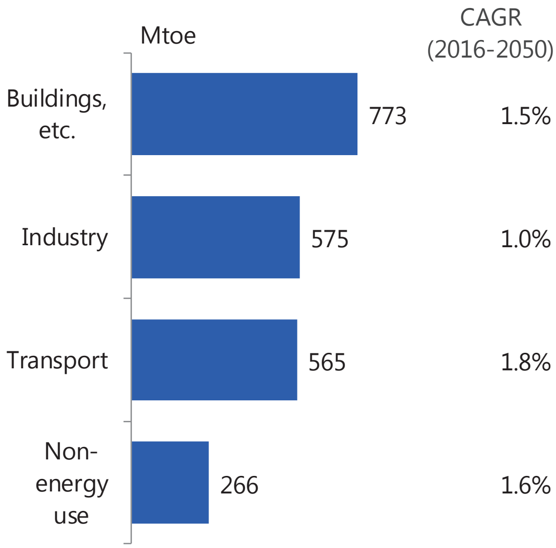
Final energy consumption (Asia, by sector)

Asia

2016	→	2050
3.7 Gtoe	(1.6 times)	**5.9** Gtoe



Changes (2016-2050)

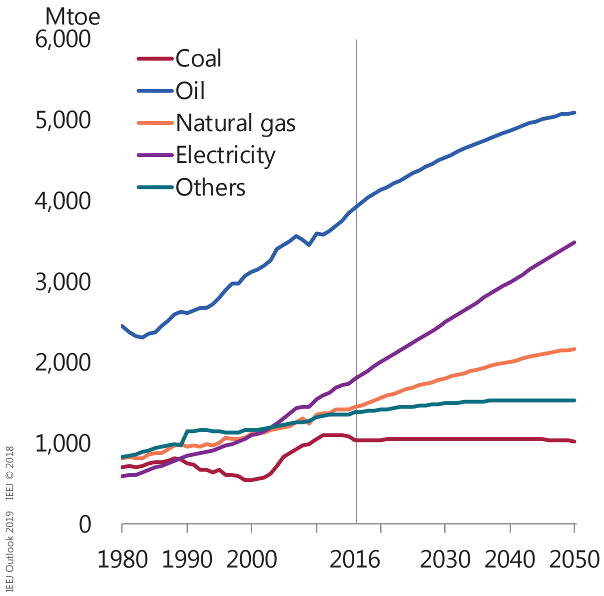


Reference Scenario

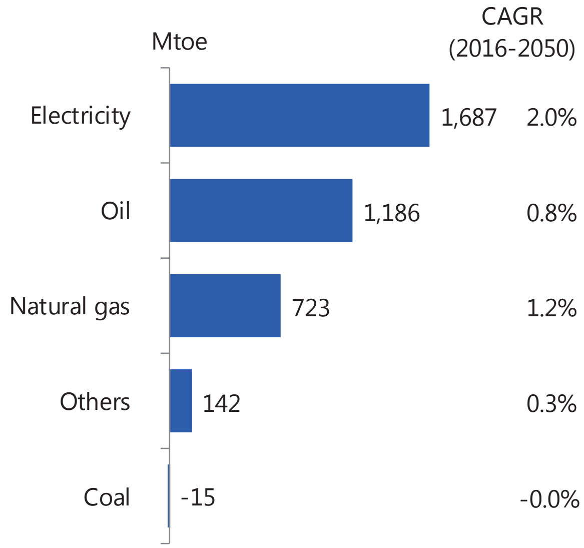
Final energy consumption (by source)

World

2016	→	2050
9.6 Gtoe	(1.4 times)	**13.3** Gtoe



Changes (2016-2050)

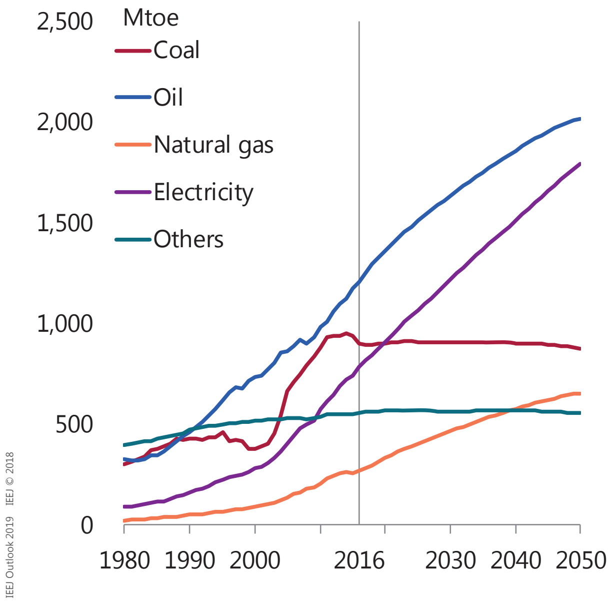


Reference Scenario

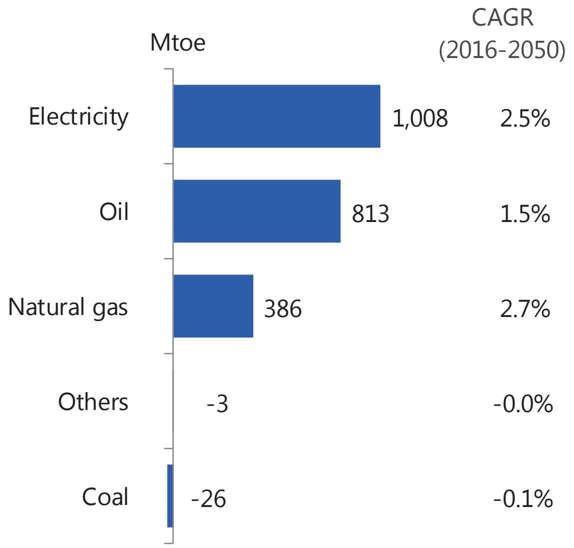
Final energy consumption (Asia, by source)

Asia

2016	→	2050
3.7 Gtoe	(1.6 times)	**5.9** Gtoe



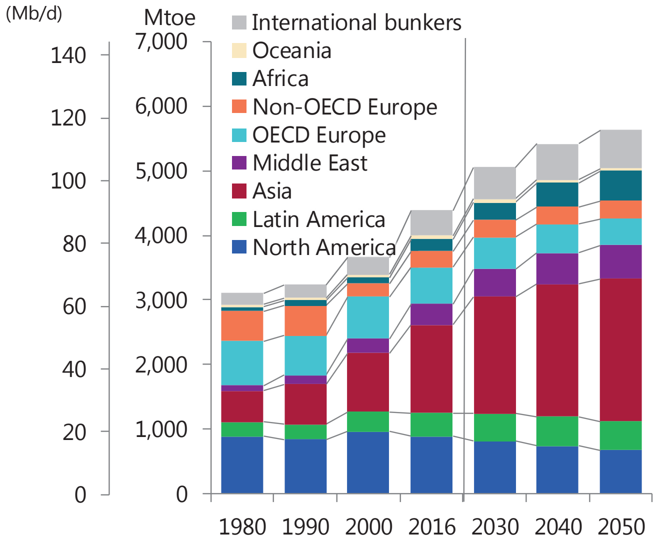
Changes (2016-2050)



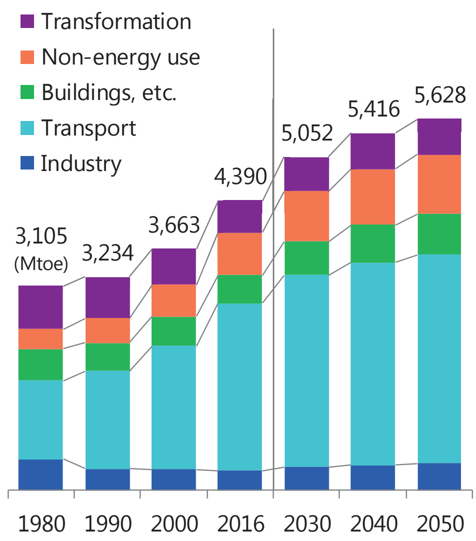
Reference Scenario

Oil consumption

By region



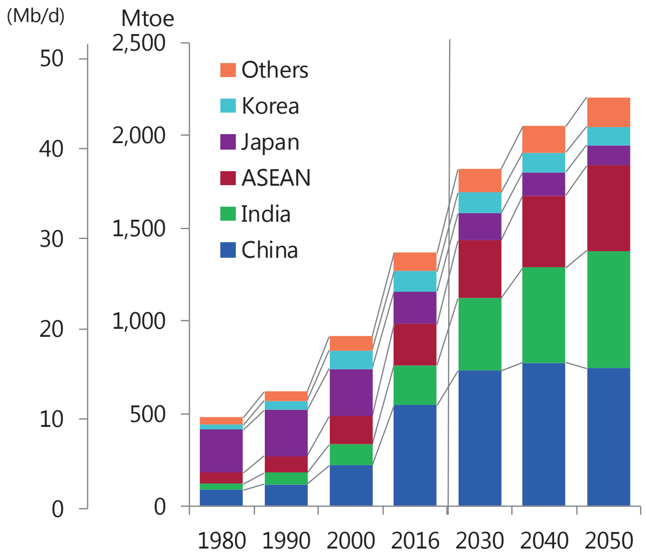
By sector



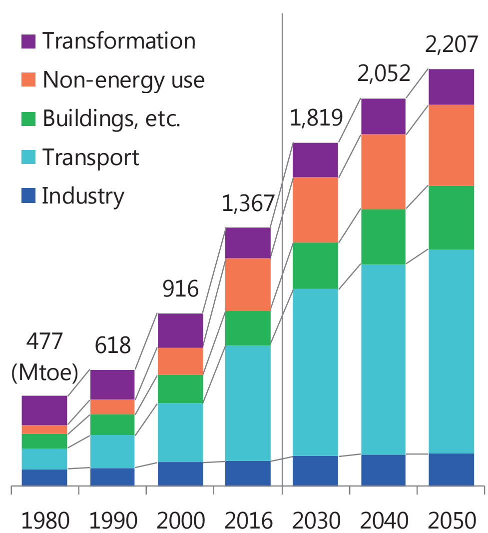
Reference Scenario

Oil consumption (Asia)

By region

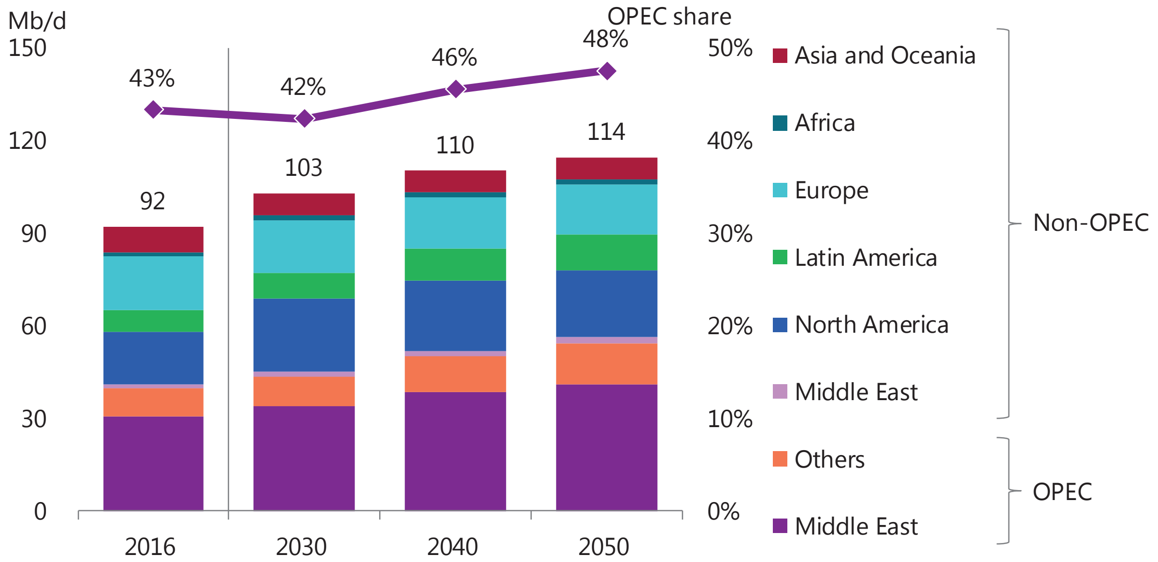


By sector



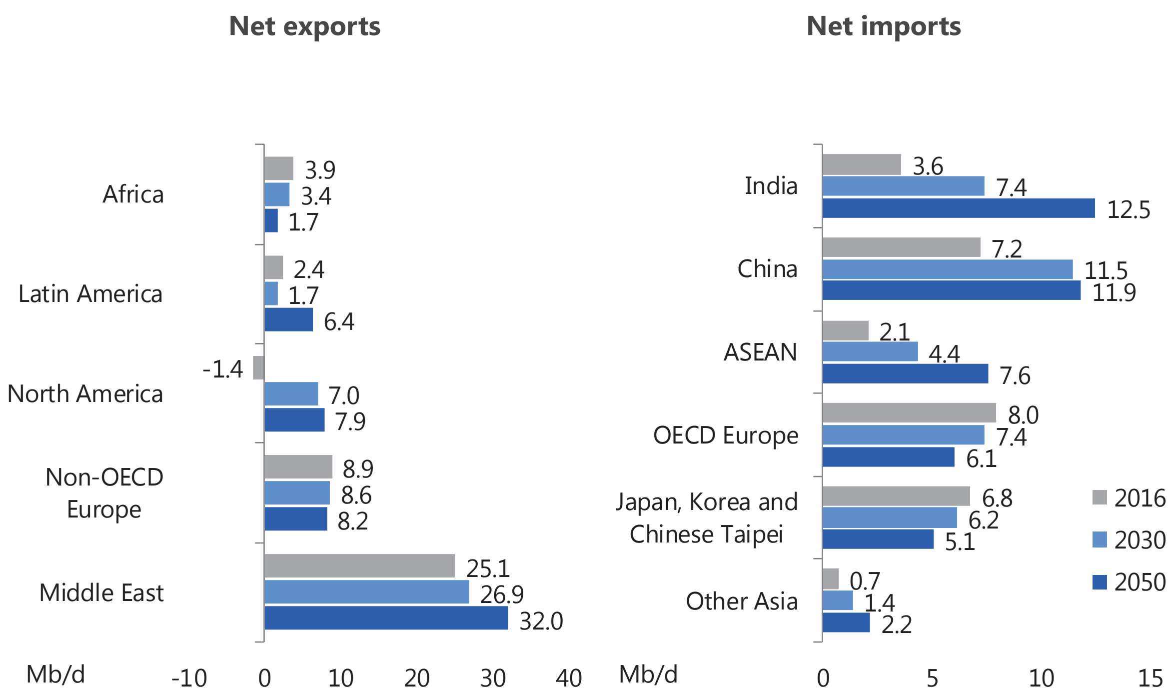
Reference Scenario

Crude oil production

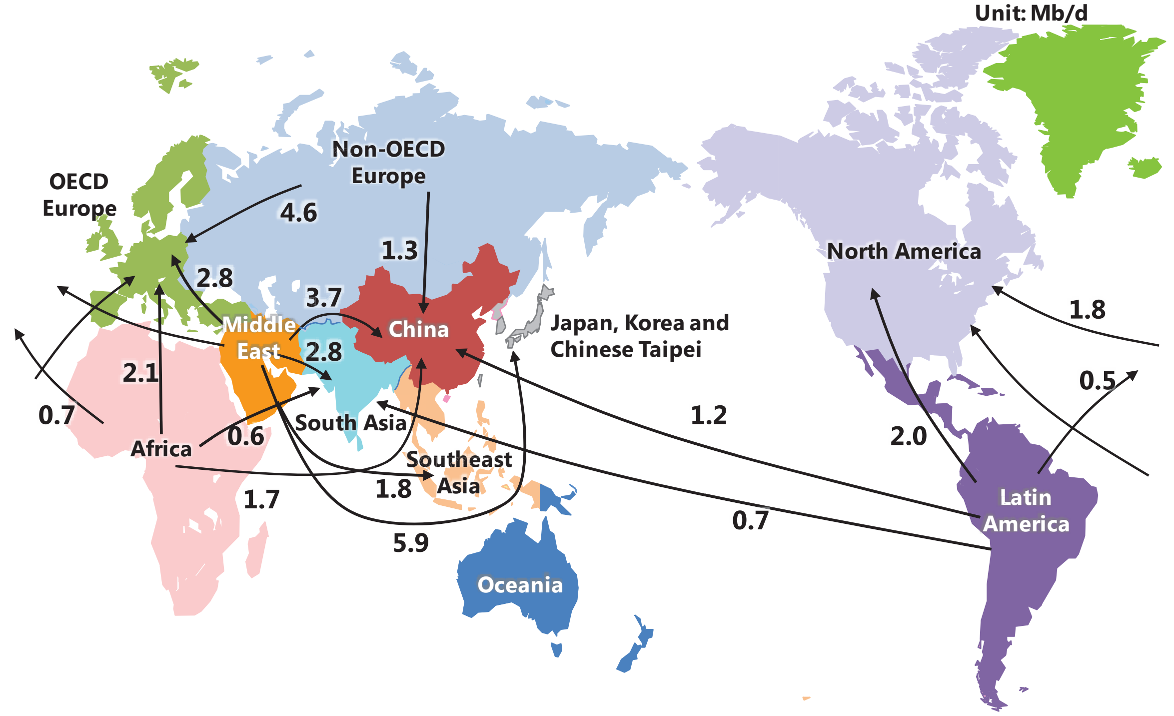


Reference Scenario

Oil net exports / imports

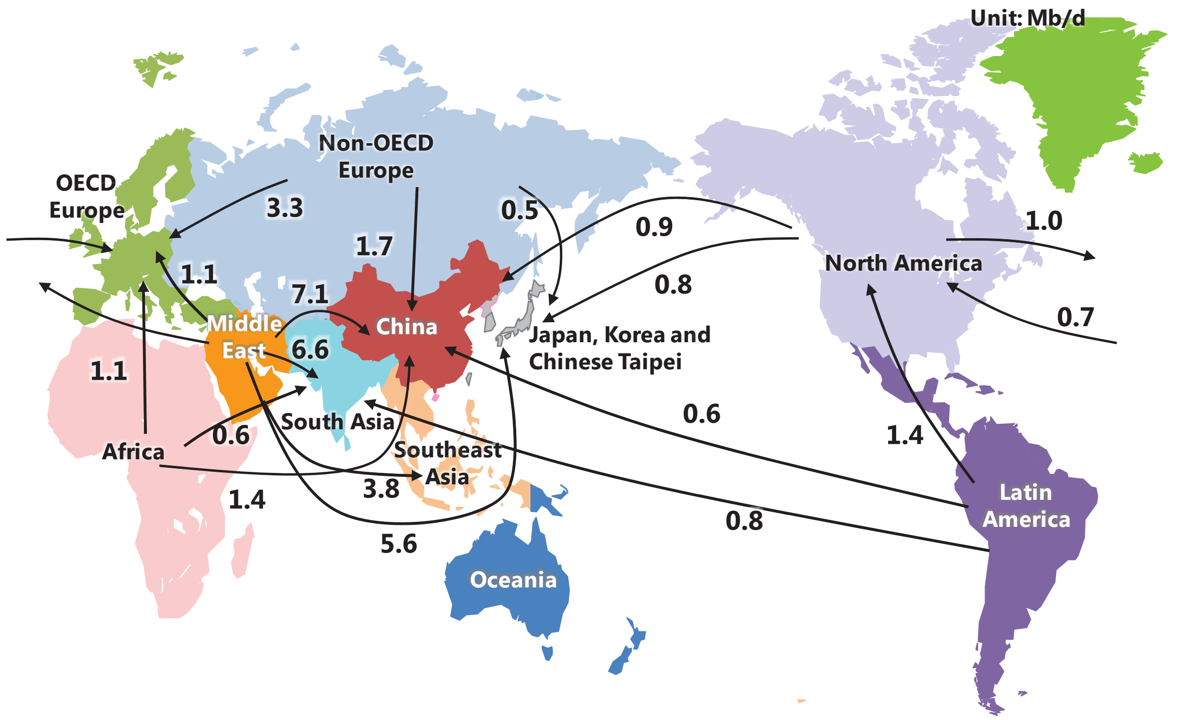


Major crude oil trade flows (2017)



Reference Scenario

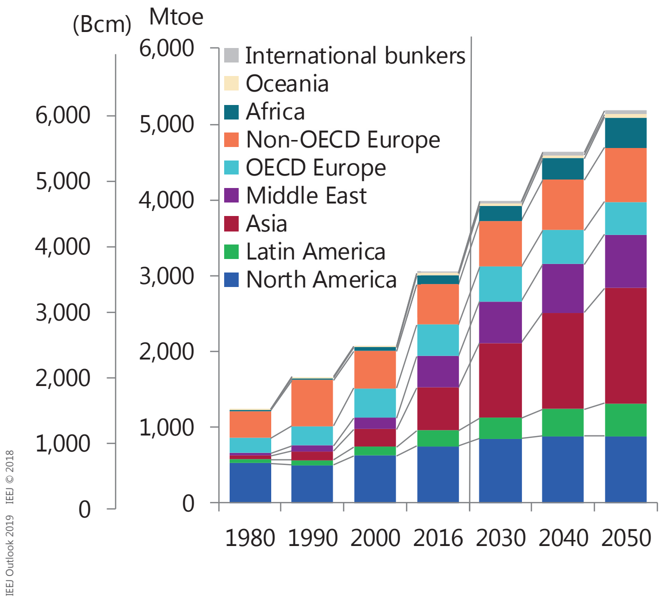
Major crude oil trade flows (2030)



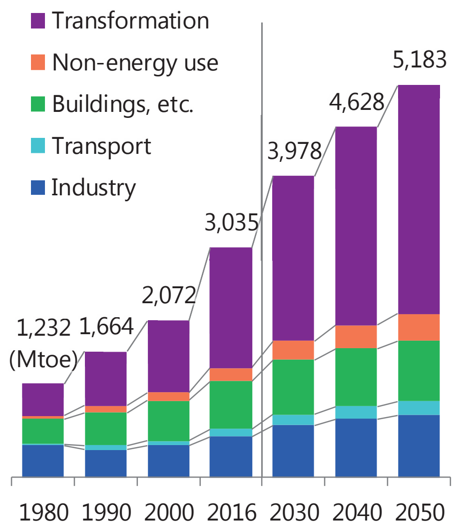
Reference Scenario

Natural gas consumption

By region



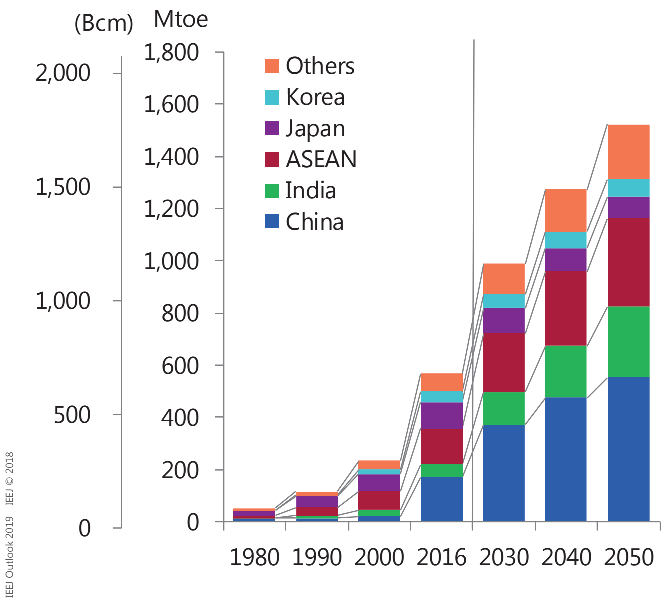
By sector



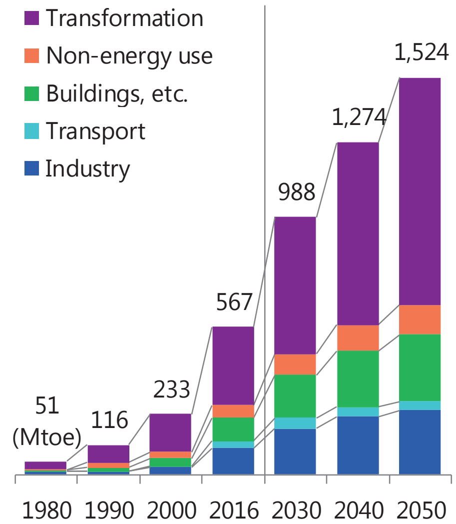
Reference Scenario

Natural gas consumption (Asia)

By region

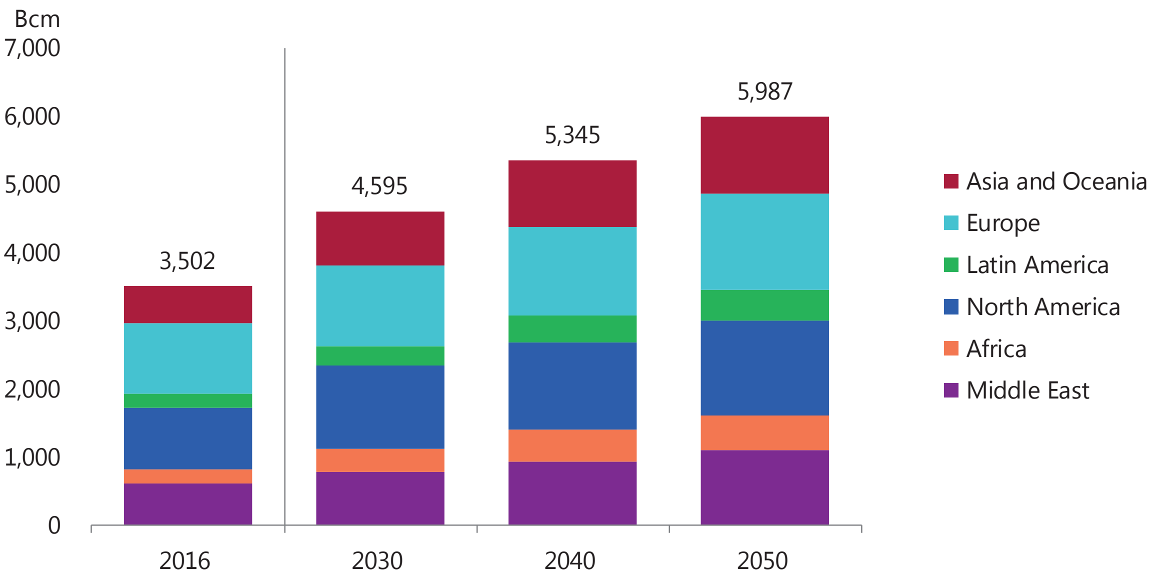


By sector



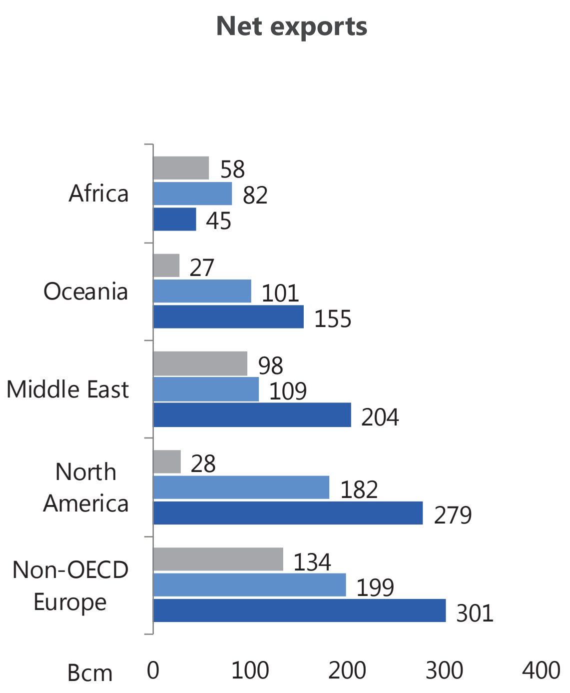
Reference Scenario

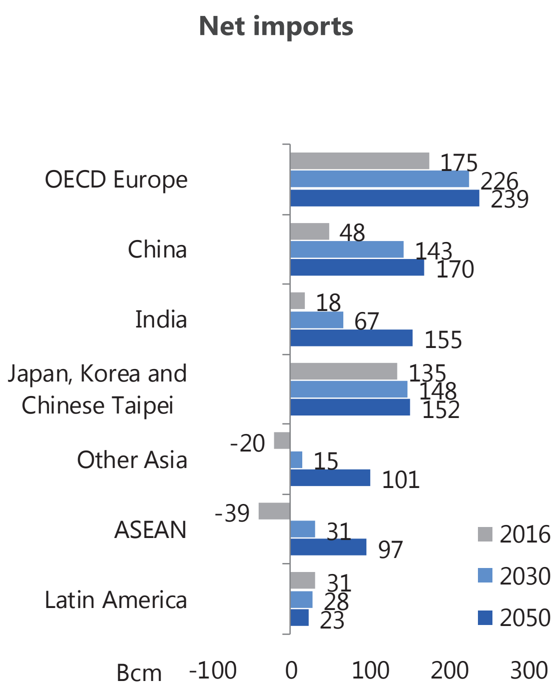
Natural gas production



Reference Scenario

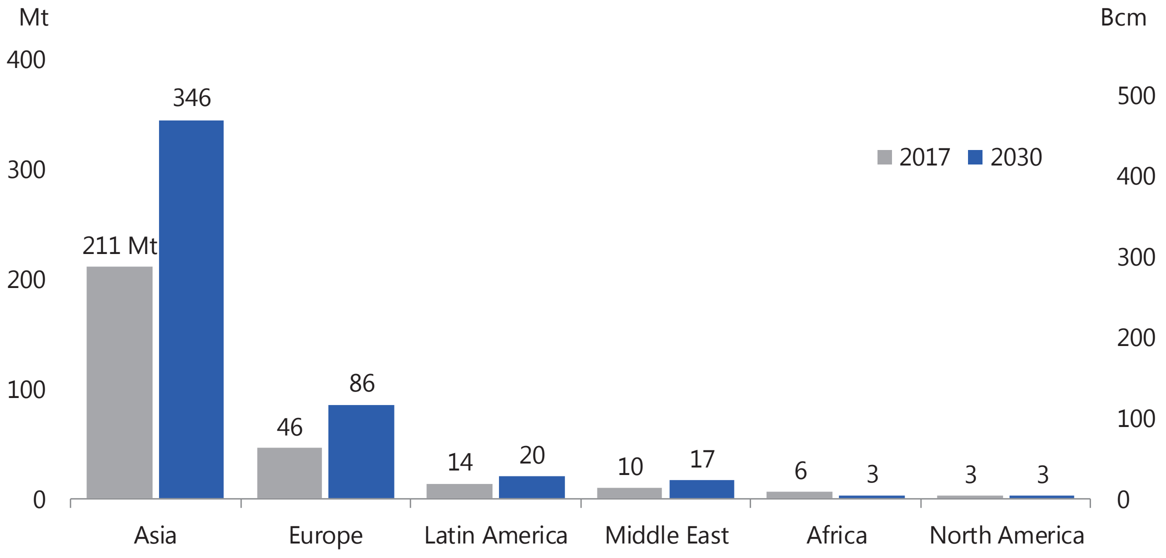
Natural gas net exports / imports



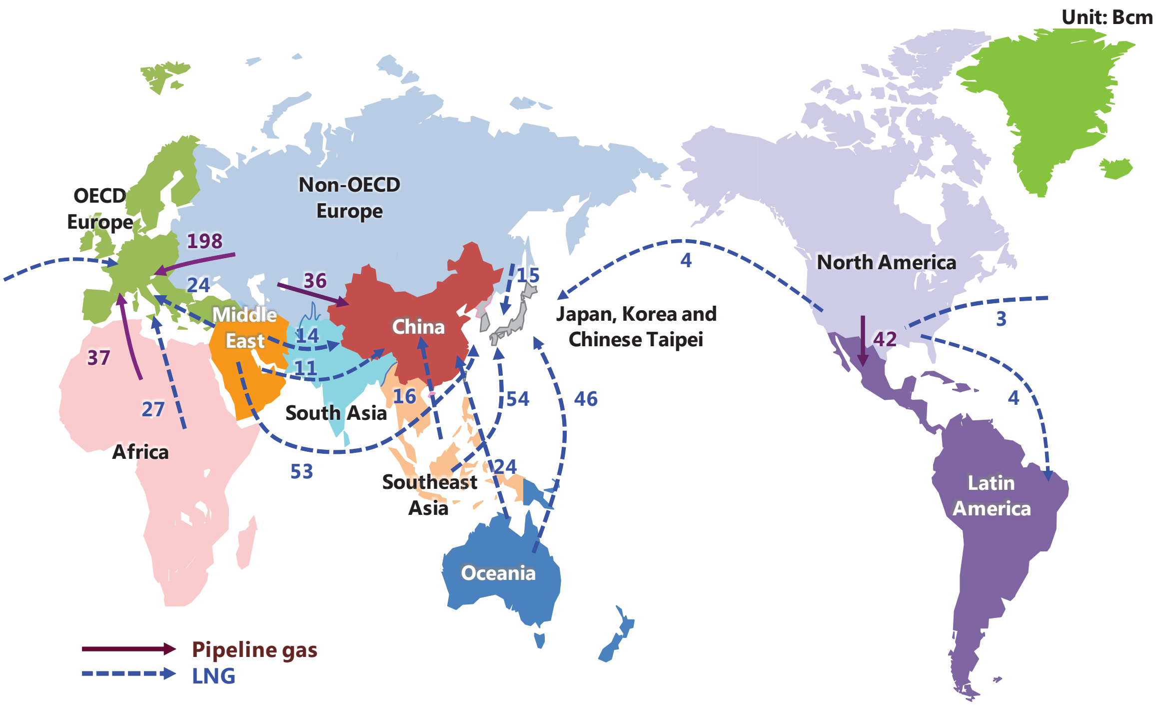


Reference Scenario

LNG imports

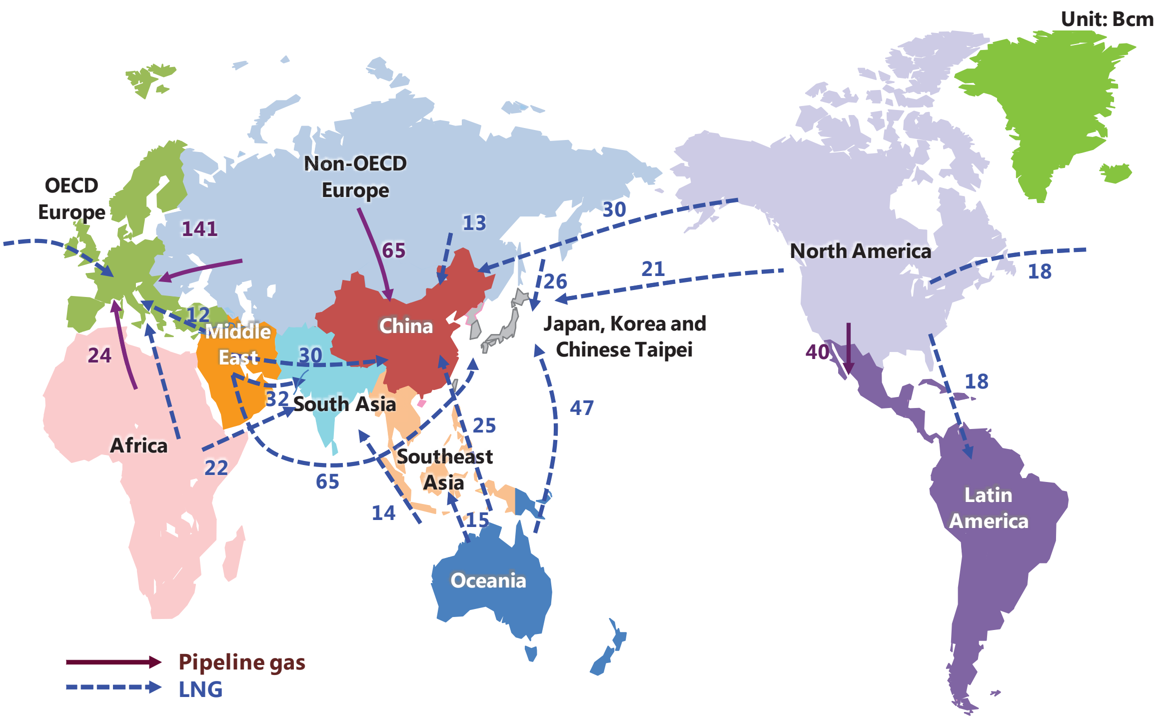


Major natural gas trade flows (2017)



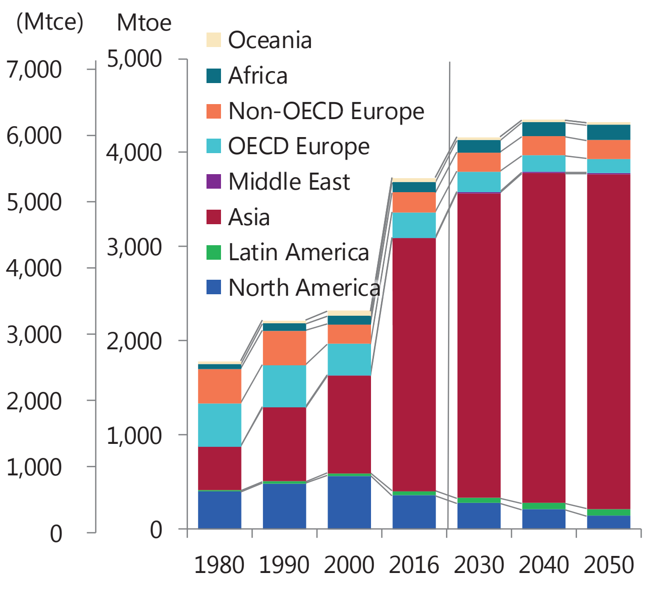
Reference Scenario

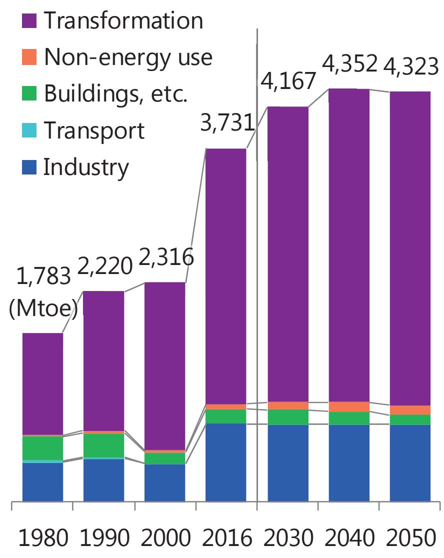
Major natural gas trade flows (2030)



Reference Scenario

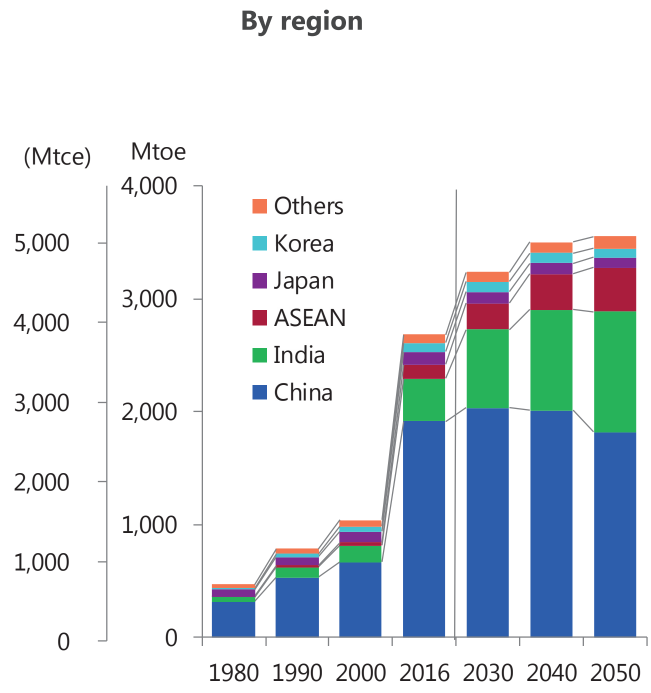
Coal consumption

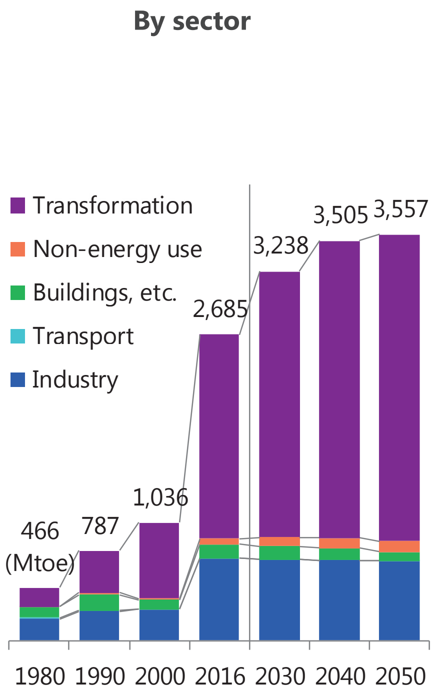




Reference Scenario

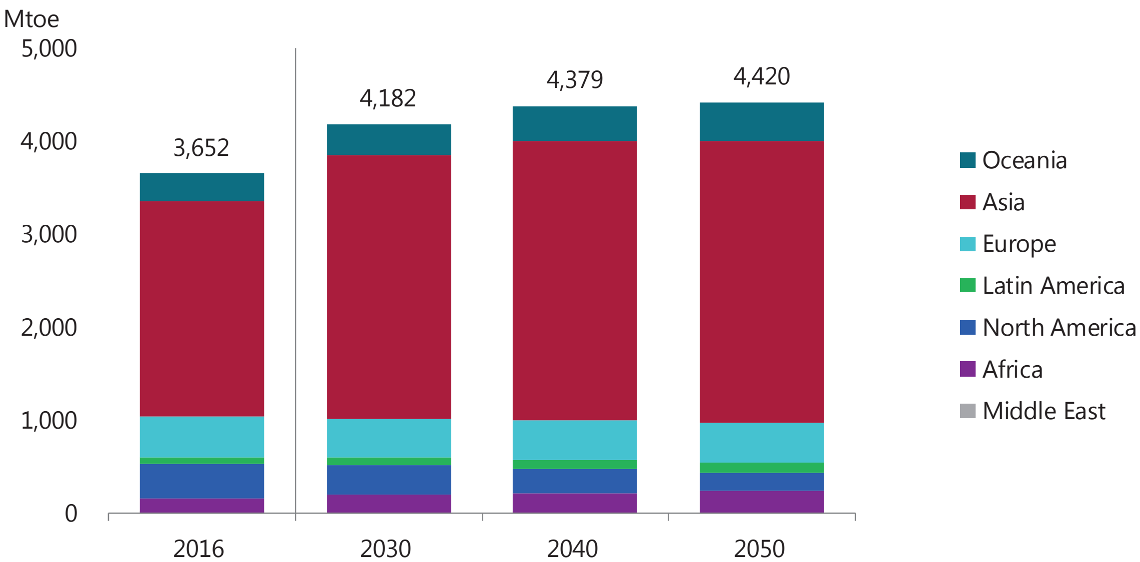
Coal consumption (Asia)





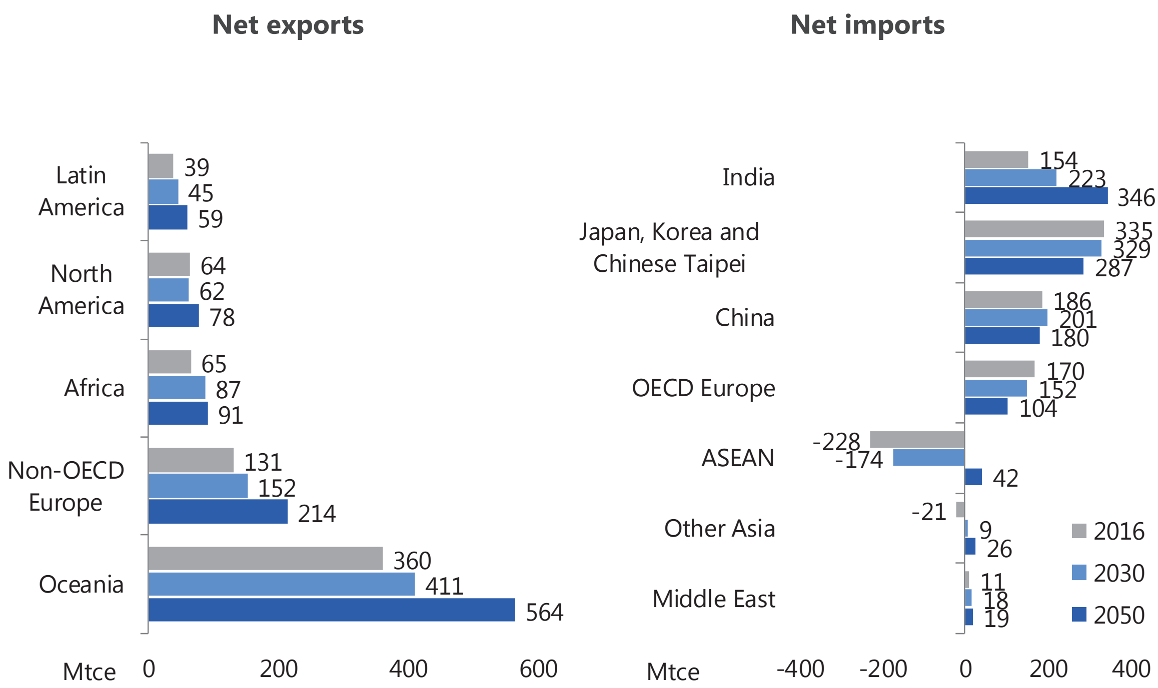
Reference Scenario

Coal production

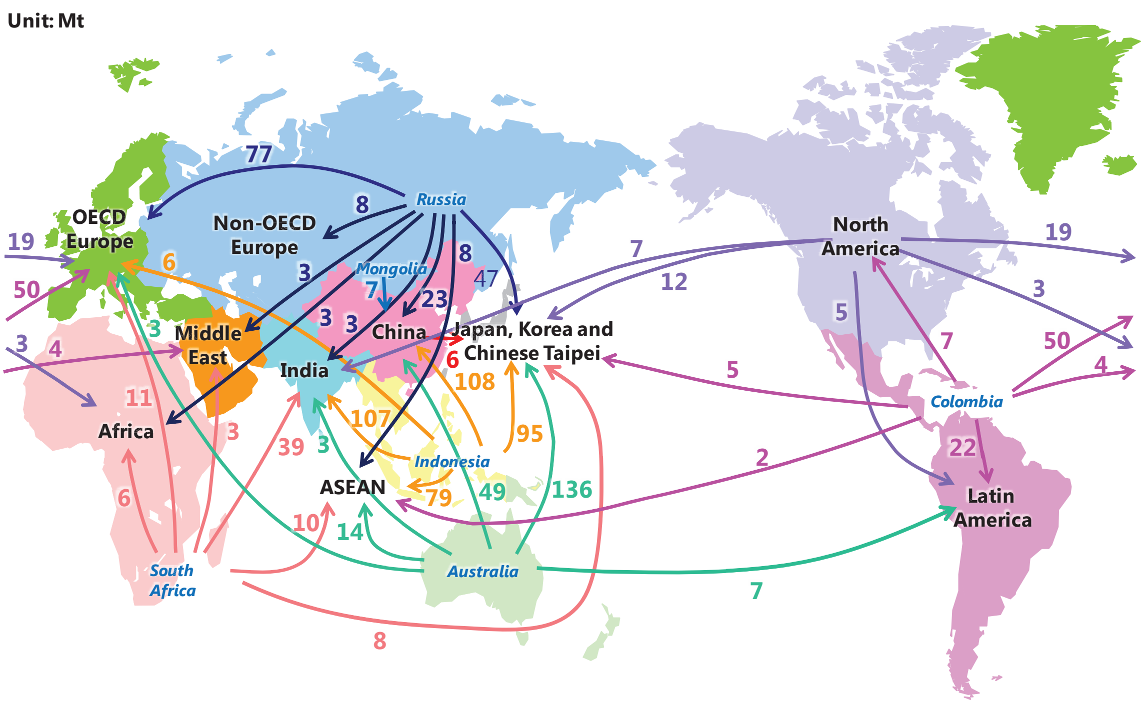


Reference Scenario

Coal net exports / imports



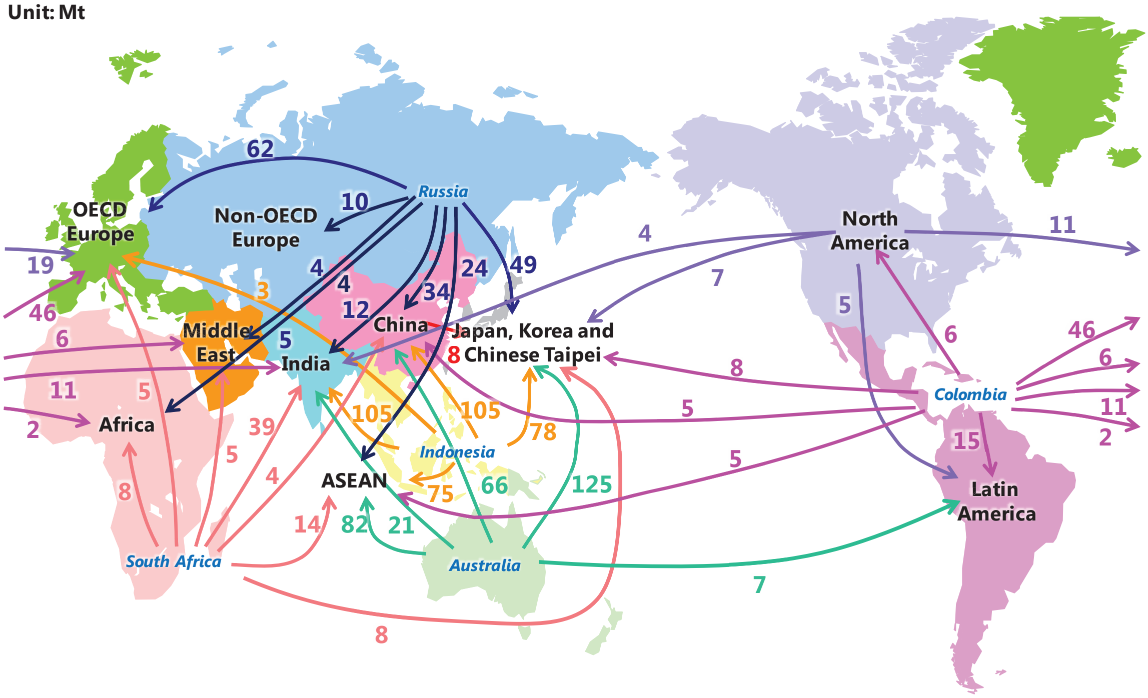
Major steam coal trade flows (2017)



Reference Scenario

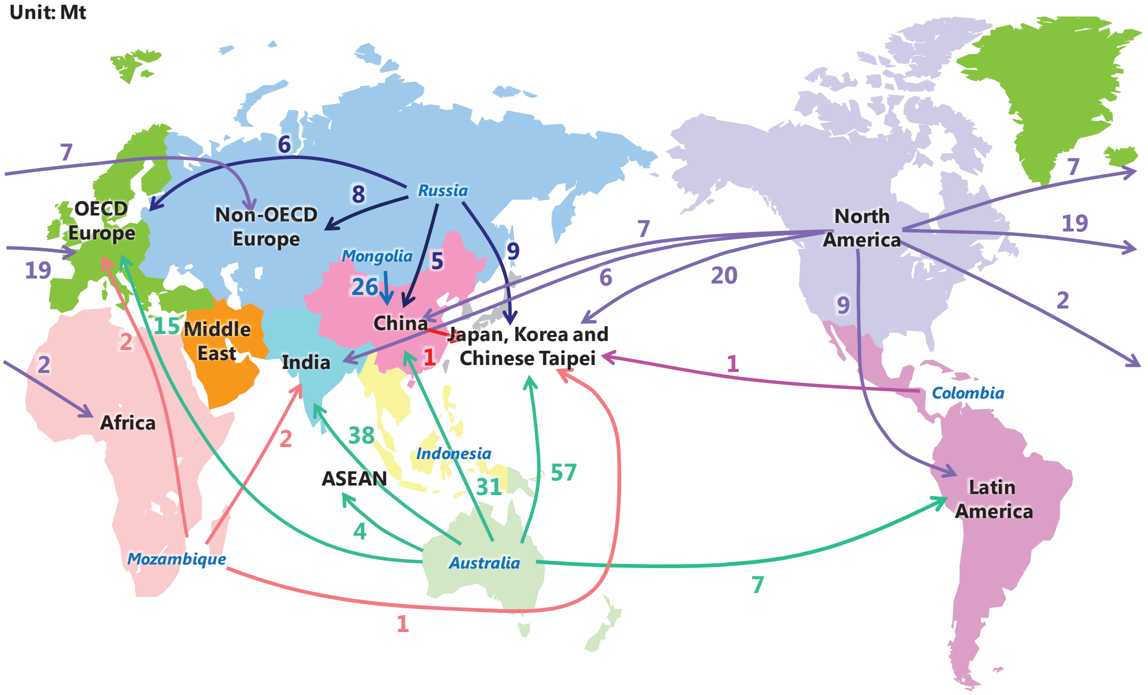
Major steam coal trade flows (2030)

Unit: Mt



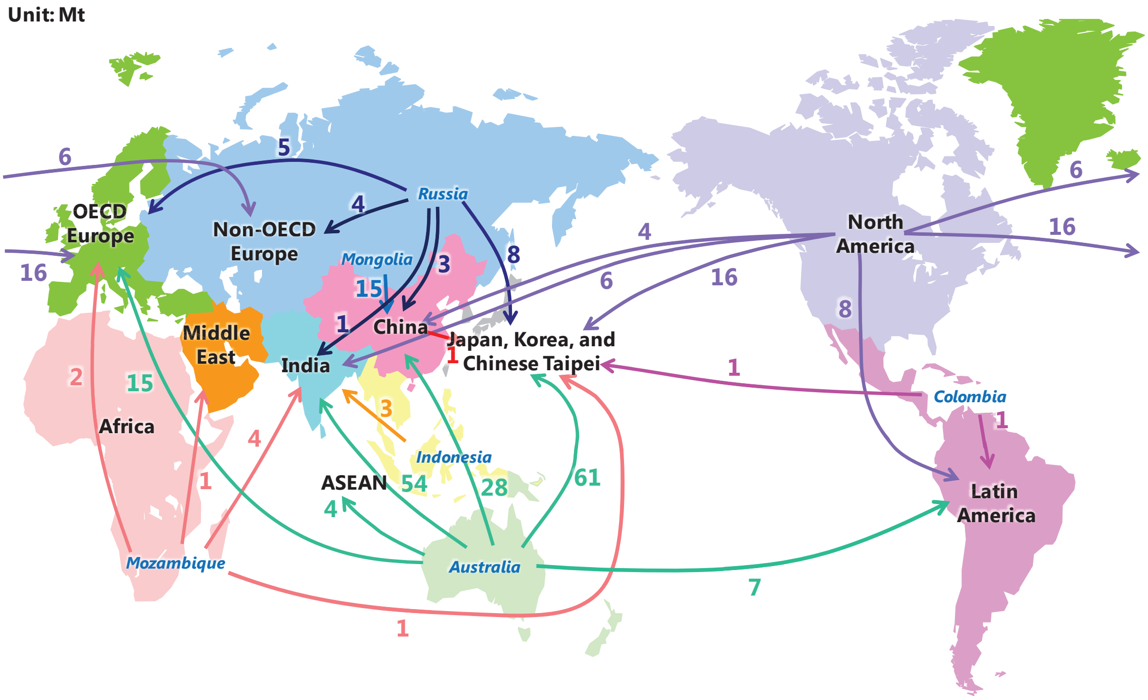
Major coking coal trade flows (2017)

Unit: Mt



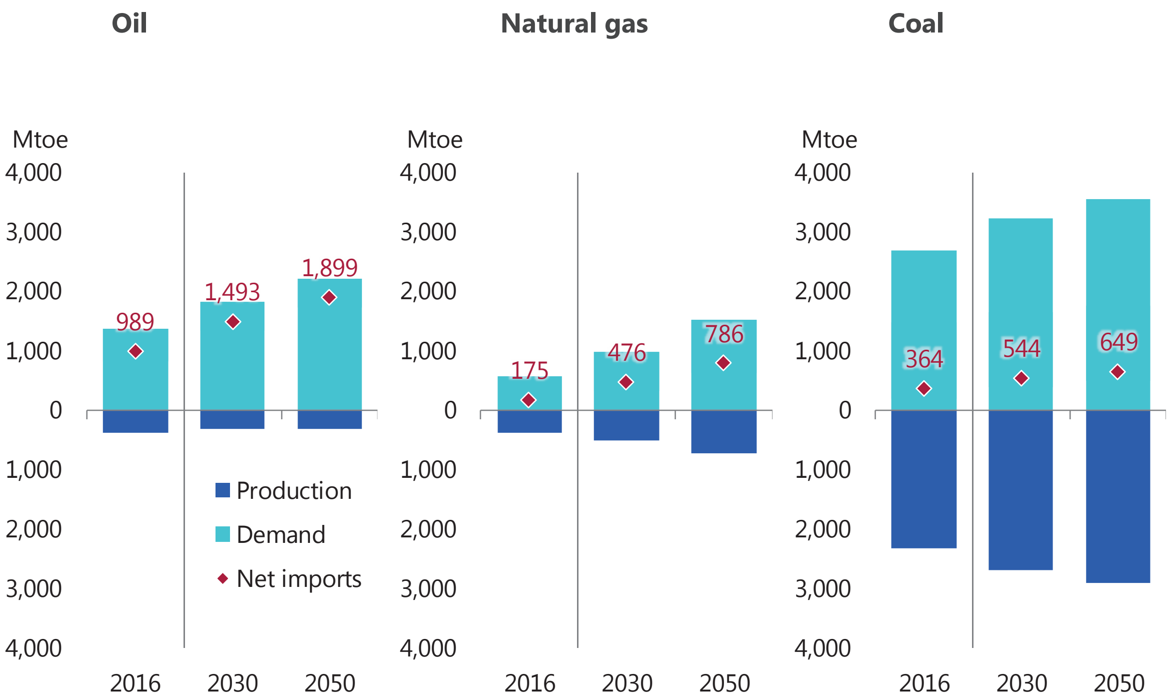
Reference Scenario

Major coking coal trade flows (2030)



Reference Scenario

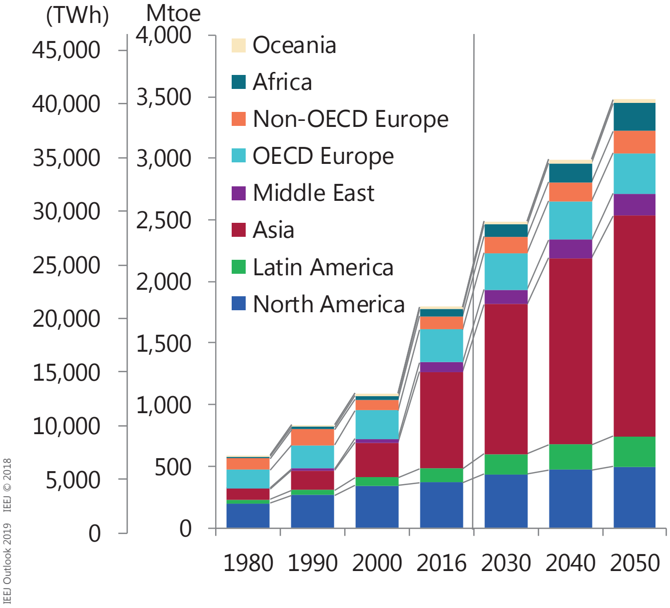
Fossil fuel supply / demand balances (Asia)



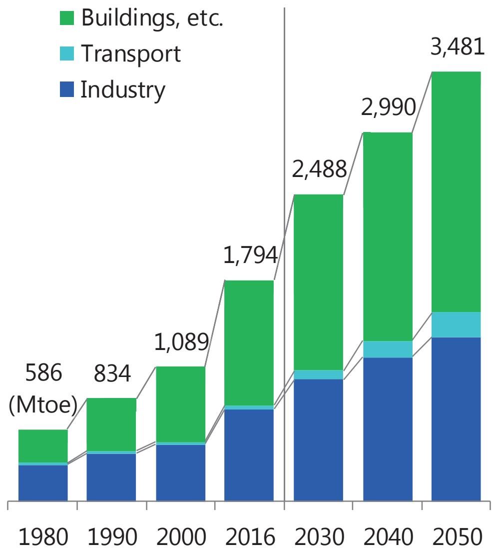
Reference Scenario

Electricity final consumption

By region



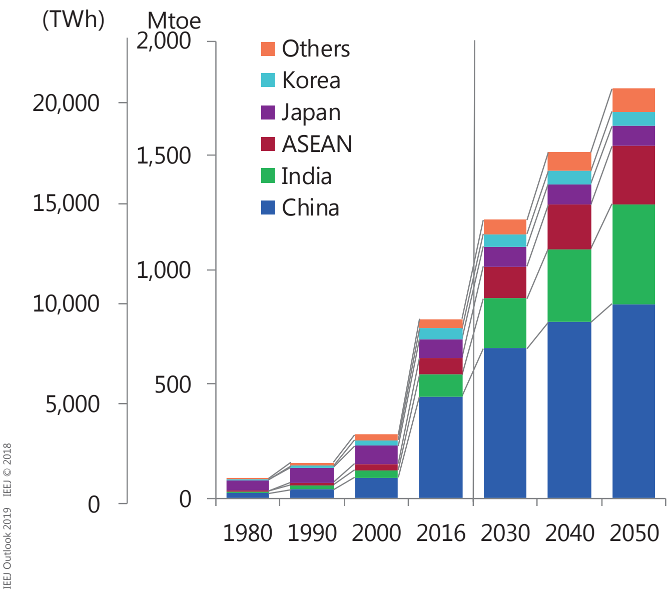
By sector



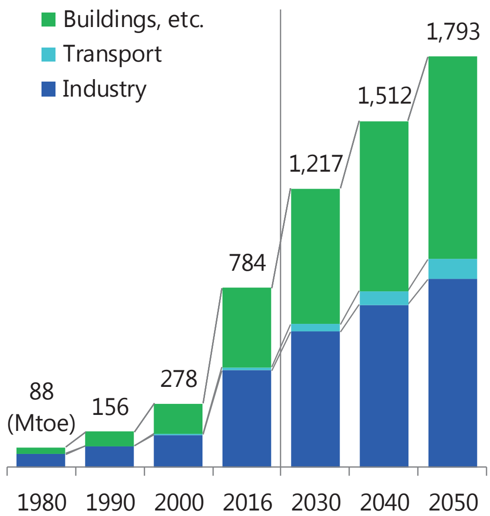
Reference Scenario

Electricity final consumption (Asia)

By region



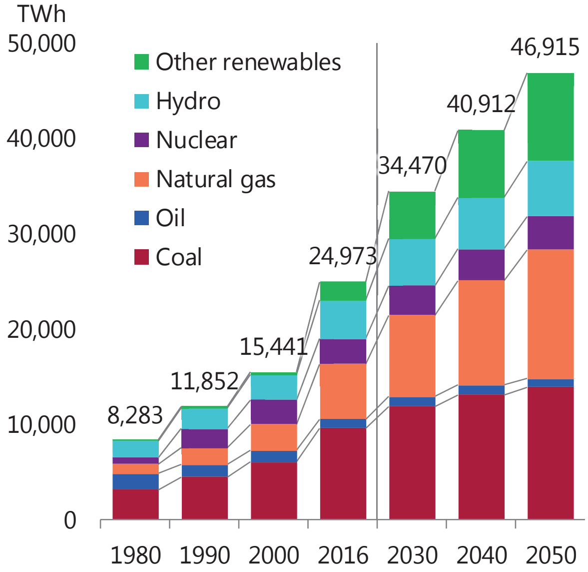
By sector



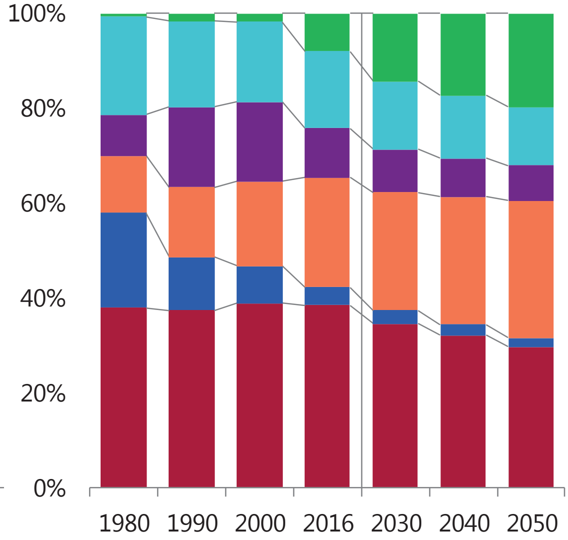
Reference Scenario

Power generation mix

Electricity generated



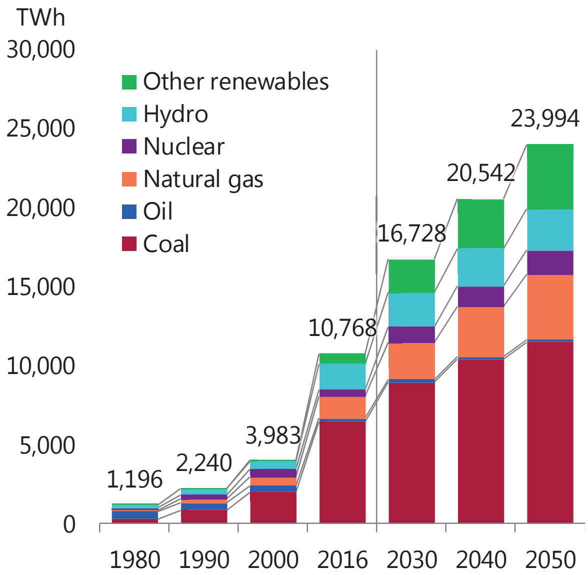
Share



Reference Scenario

Power generation mix (Asia)

Electricity generated



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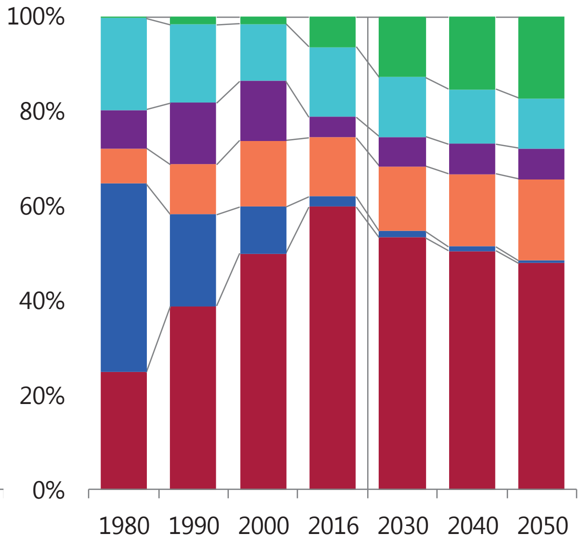
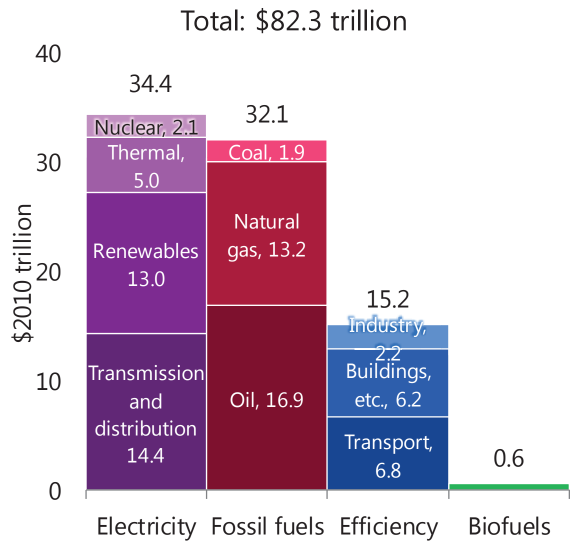


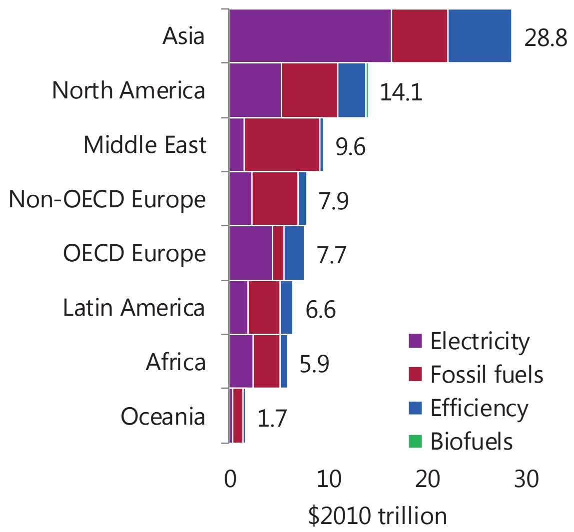
Reference Scenario

Energy-related investments (2017 - 2050)

By sector



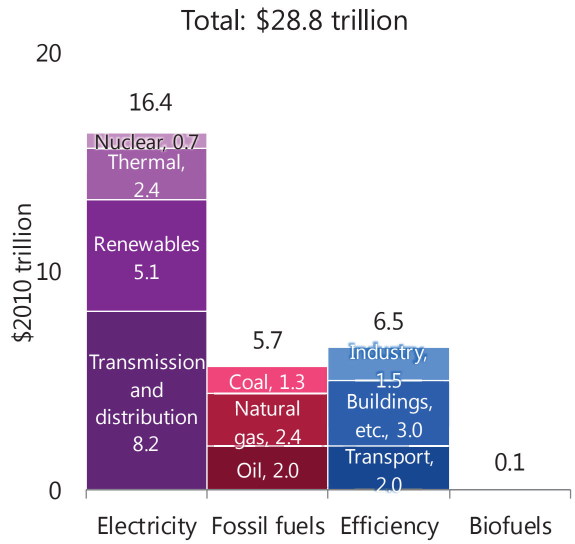
By region and sector



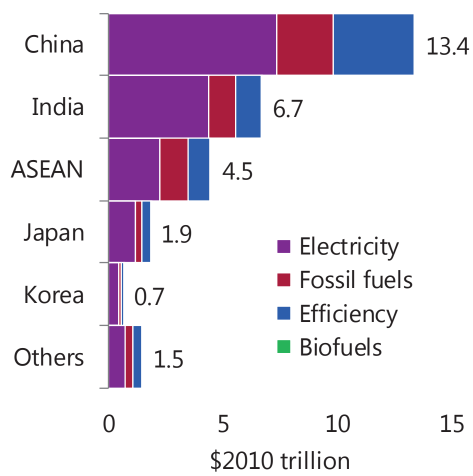
Reference Scenario

Energy-related investments (Asia, 2017 - 2050)

By sector



By region and sector

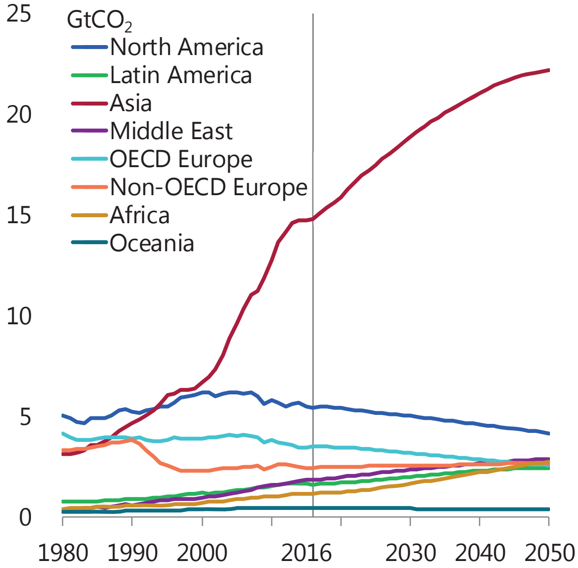


Reference Scenario

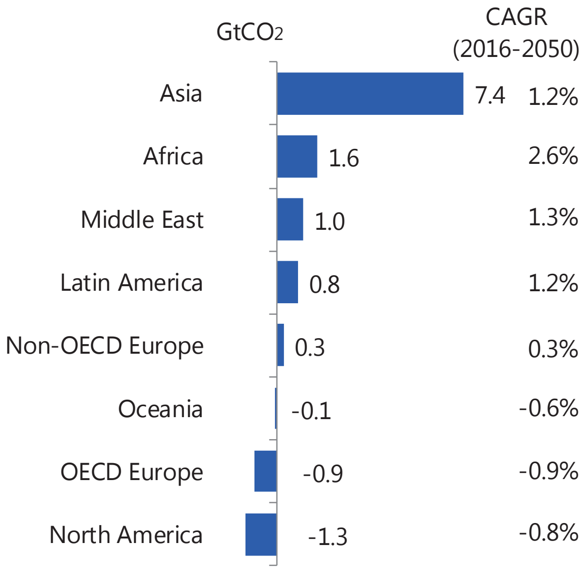
CO_2 emissions

World

2016	→	2050
32.4 Gt	(×1.3)	**41.9** Gt



Changes (2016-2050)

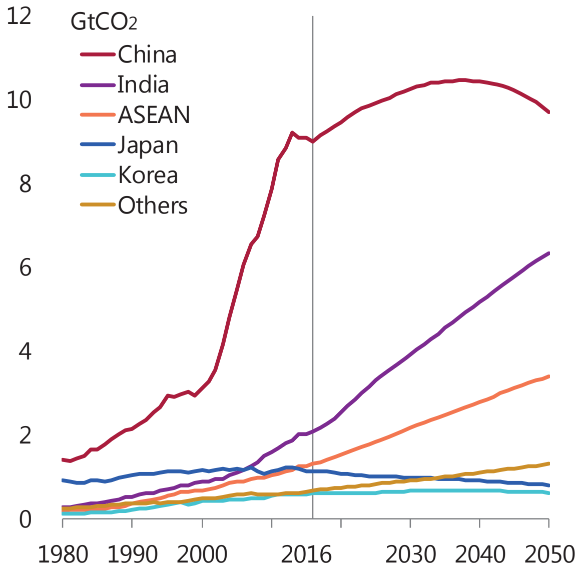


Reference Scenario

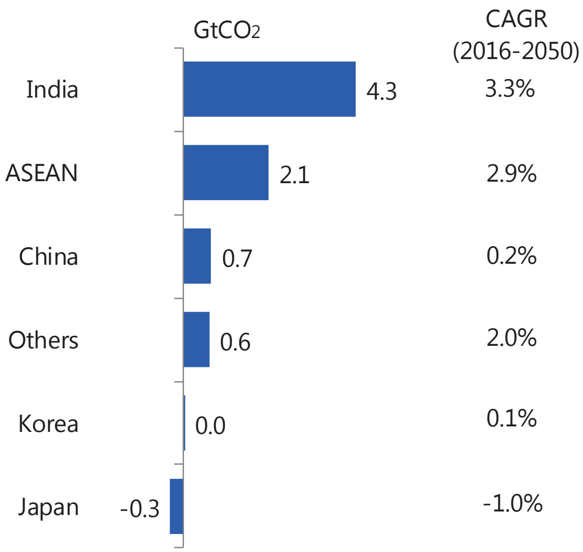
CO_2 emissions (Asia)

Asia

2016	→	2050
14.8 Gt	(×1.5)	**22.4** Gt



Changes (2016-2050)



Advanced Technologies Scenario

Advanced Technologies Scenario

Major technological assumptions

In the Advanced Technologies Scenario, each country further enhances policies on energy security and address climate change. Technology developments and international technology transfers are promoted to further penetration of advanced technologies.

Introducing and enhancing environmental regulations and national targets

Environment tax, emissions trading, RPS, subsidy, FIT, efficiency standards, automobile fuel efficiency standard, low carbon fuel standard, energy efficiency labelling, national targets, etc.

Promoting technology development and international technology cooperation

R&D investment expansion, international cooperation on energy efficient technology (steelmaking, cement and other areas), support for establishing energy efficiency standards, etc.

Demand side technologies

■ Industry

Under sectoral and other approaches, best available technologies on industrial processes (for steelmaking, cement, paper-pulp and oil refining) will be deployed globally.

■ Transport

Clean energy vehicles (highly fuel efficient vehicles, hybrid vehicles, plug-in hybrid vehicles, electric vehicles, fuel cell vehicles) will diffuse further.

■ Buildings

Efficient electric appliances (refrigerators, TVs, etc.), highly efficient water-heating systems (heat pumps, etc.), efficient air conditioning systems and efficient lighting will diffuse further, with heat insulation enhanced.

Supply side technologies

■ Renewable energies

Wind power generation, solar photovoltaic power generation, concentrated solar power (CSP) generation, biomass-fired power generation and biofuels will penetrate further.

■ Nuclear

Nuclear power plant construction will be accelerated with capacity factor improved.

■ Highly efficient fossil fuel-fired power generation technologies

Coal-fired power plants (SC, USC, A-USC, IGCC) and natural gas–fired more advanced combined cycle (MACC) plants will penetrate further.

■ Technologies for next-generation transmission and distribution networks

Lower loss type of transformation and voltage regulator will penetrate further.

■ Carbon capture and storage

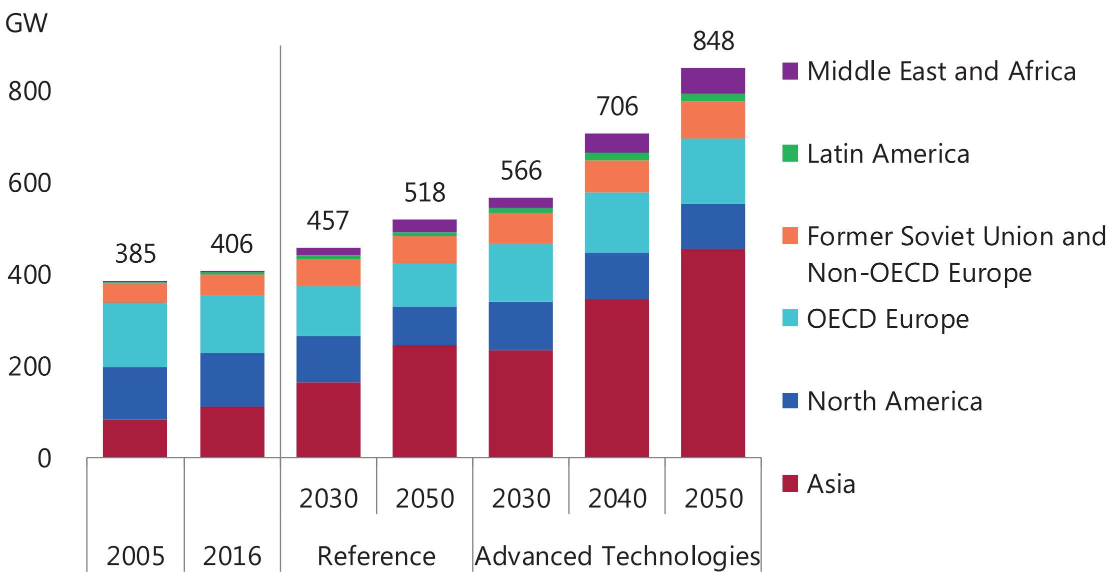
*SC: Super Critical, USC: Ultra Super Critical, A-USC: Advanced Ultra Super Critical

Penetration of low-carbon technologies

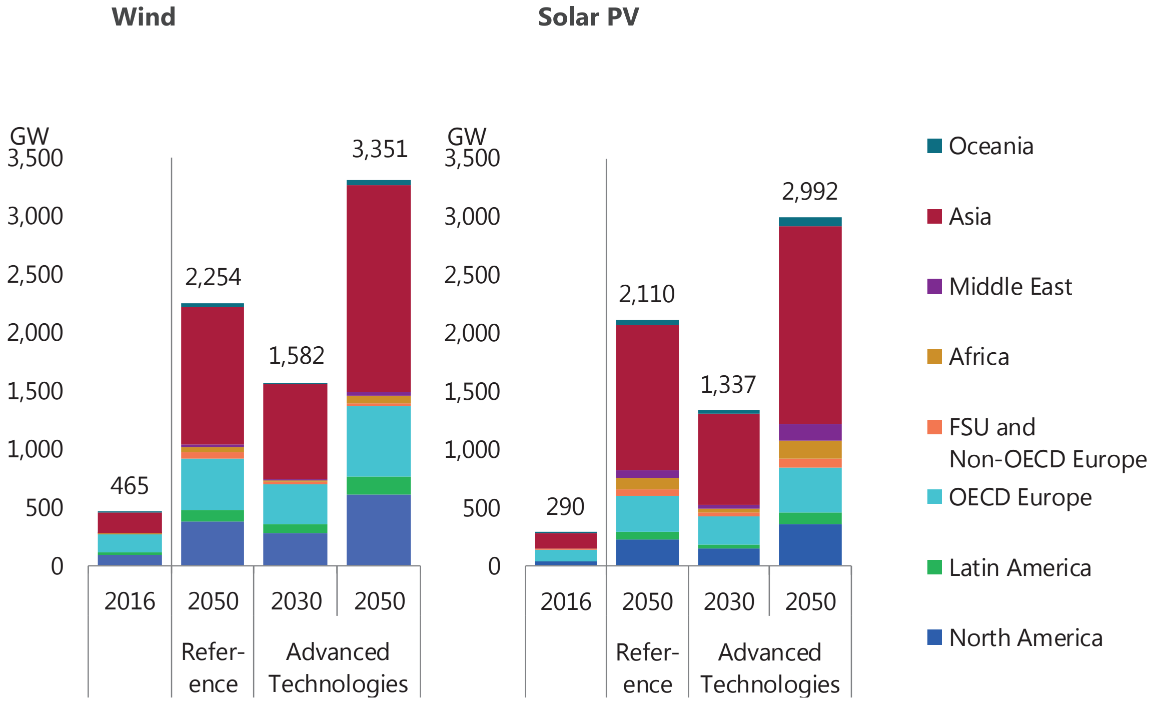
2016 → 2050 (Reference 2050)

	OECD	Non-OECD
Thermal power plant	Maintenance of financial scheme for initial investment. Share of IGCC in install 0→ 60% (20%) Installing CCS after 2030 (Countries which have storage potential except for aquifer)	
[Thermal efficiency (stock basis)]	Natural gas: 48.4% → 56.8% (57.0%) Coal: 37.2% → 43.5% (44.3%)	Natural gas: 37.1% → 49.1% (45.9%) Coal: 35.4% → 39.3% (40.6%)
Nuclear	Maintenance of appropriate price in wholesale electricity market	Maintenance of framework for financing initial investment
[Capacity]	2016: 311 GW → 298 (217)	2016: 96 GW → 550 (302)
Renewables [Capacity]	System cost reduction Cost reduction of power system Efficient operation of power system Wind: 237 GW → 1,091 (718) Solar: 165 GW → 909 (573)	System cost reduction Low cost investment Improvement of power system Wind: 178 GW → 1,912 (1,152) Solar : 60 GW → 1,588 (946)
Biofuels	Development of next generation biofuel Higher diffusion of FFV	Cost reduction of biofuel Relating to agricultural policy
[Consumption]	55 Mtoe → 106 (69)	27 Mtoe → 81 (54)
Industry	Best available technology diffuses 100% in 2050	
Transportation	Cost reduction of high fuel efficiency of vehicles. Twice of travel distance of ZEV	
[[Average fuel efficiency of new vehicle sales]]	14.5 km/L → 39.3 (28.6)	12.9 km/L → 30.5 (21.7)
[Share in annual vehicle sales of ZEV]	0.8% → 64% (40%)	0.6% → 48% (25%)
Buildings	The pace of improvement of efficiency of newly installed appliance, equipment and insulation is twice. 15% improvement in 2050 in ratio of the Reference Scenario Electrification and clean cooking in space heating, water heater and cooking	

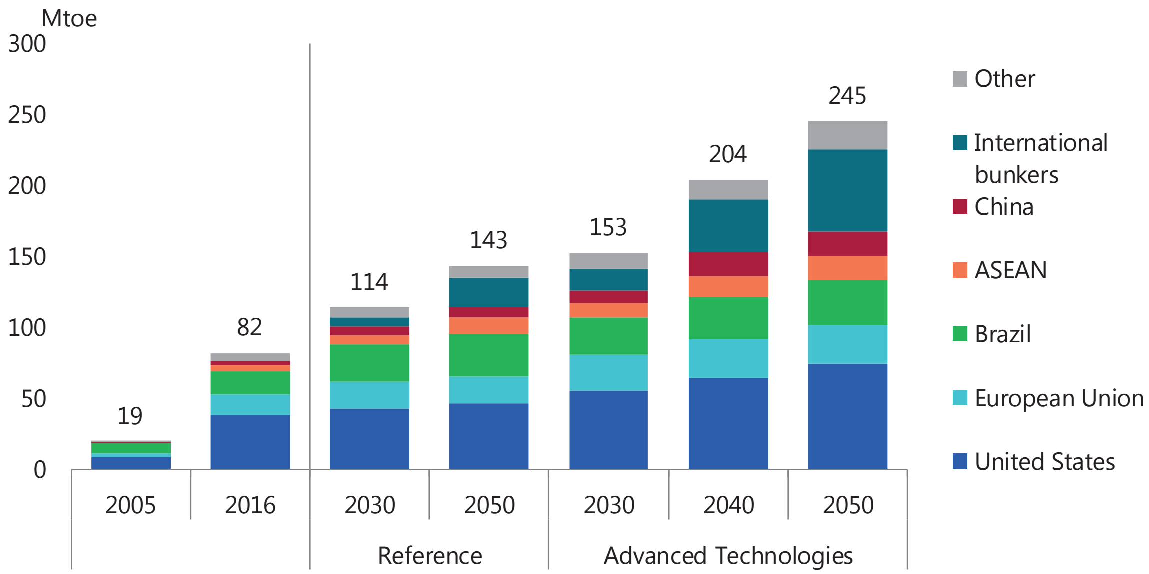
Nuclear power generation capacity



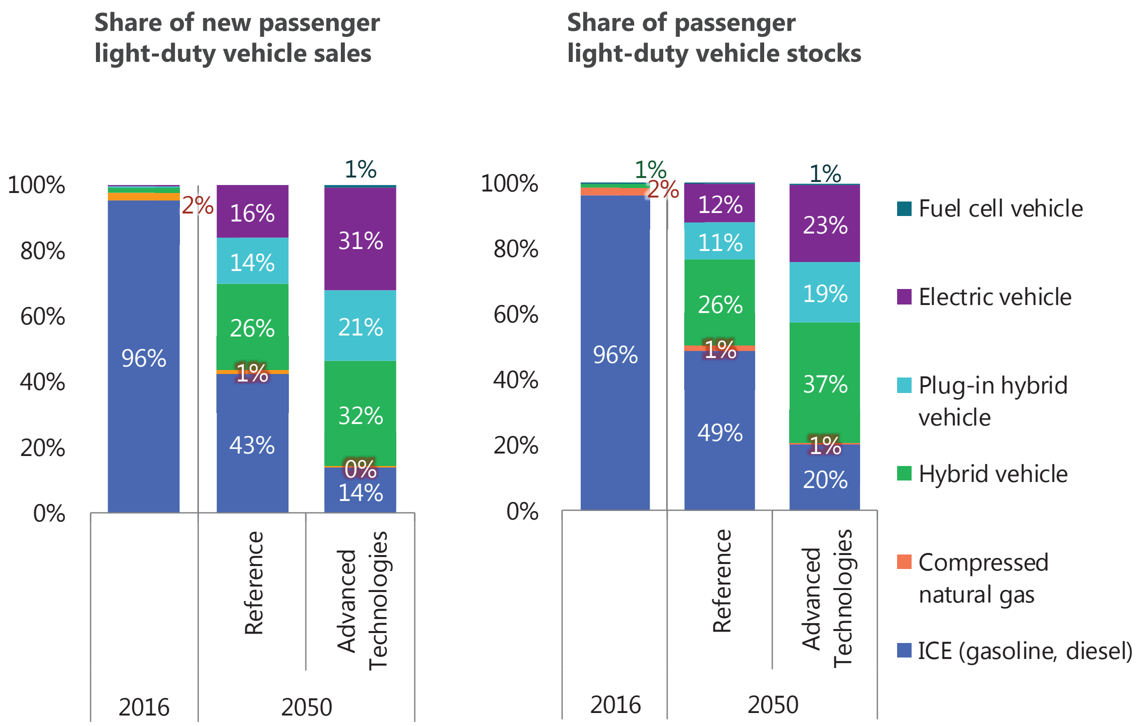
Renewable power generation capacity



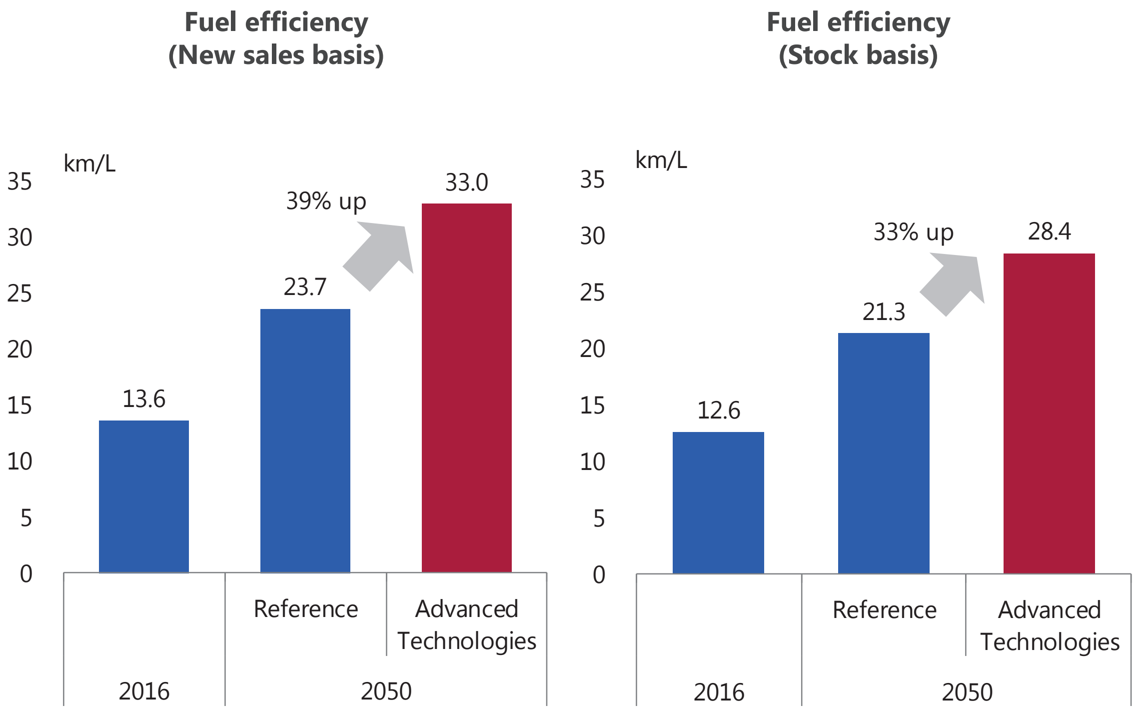
Biofuels consumption for transport



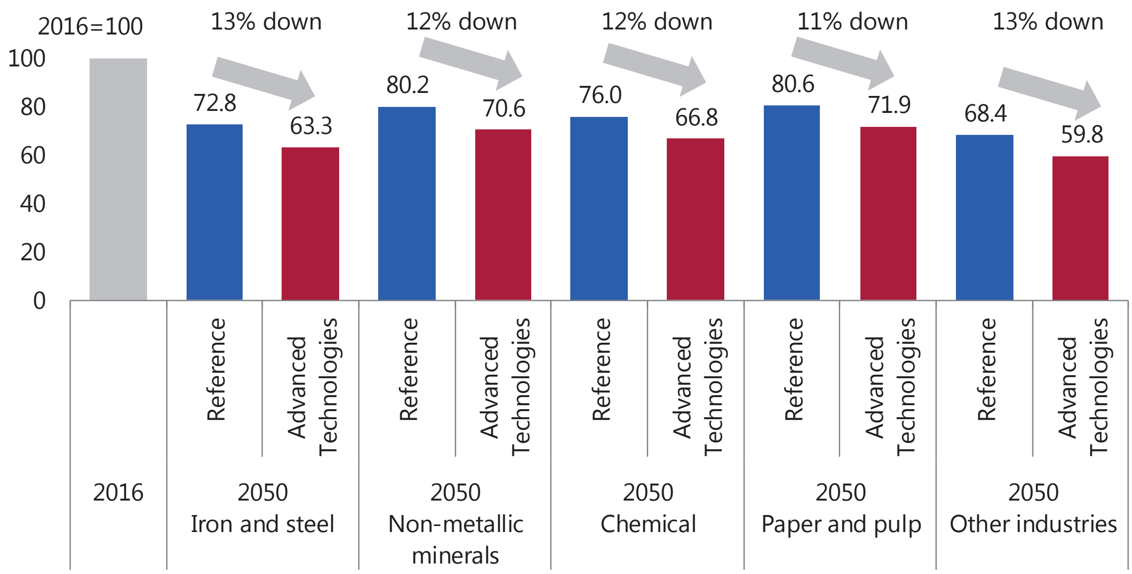
Vehicle stock and sales (by type)



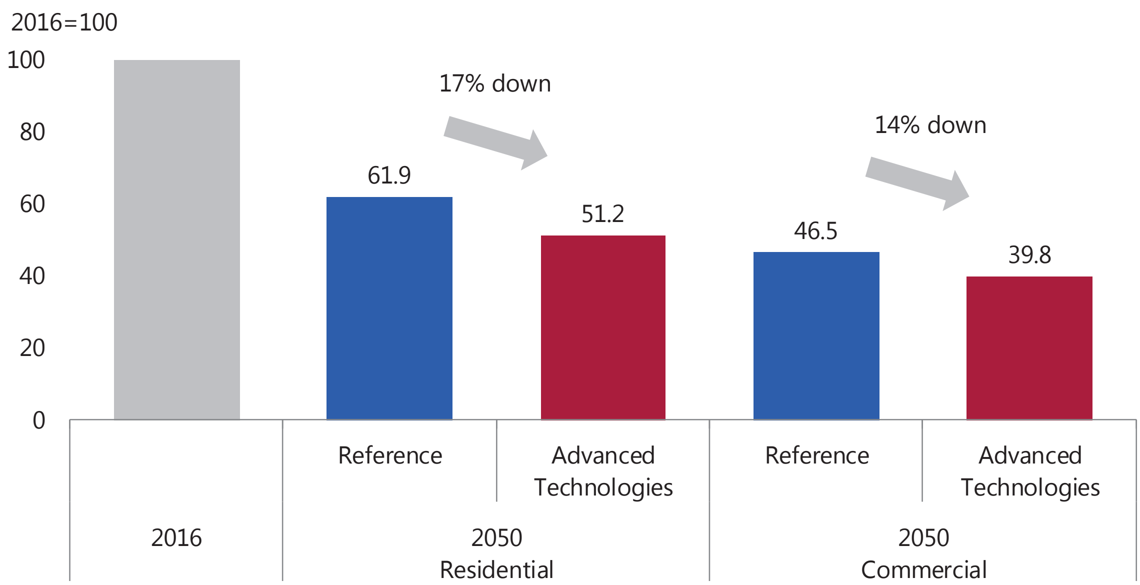
Fuel efficiency of passenger cars



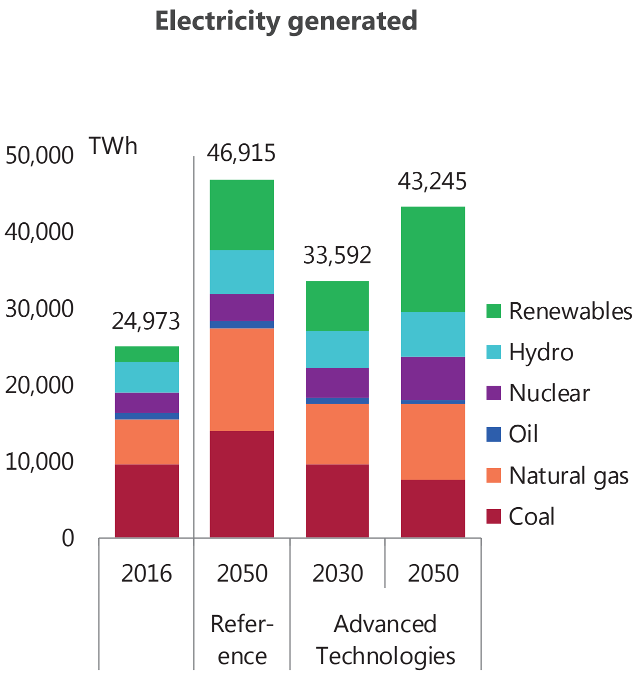
Energy intensity in industry

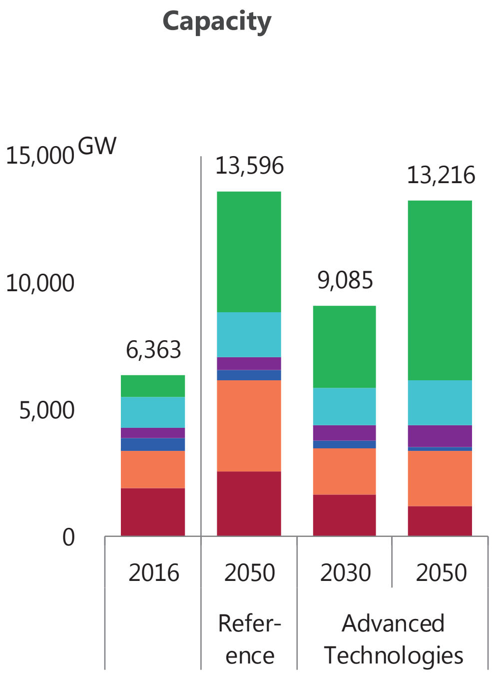


Total efficiency in the buildings sector

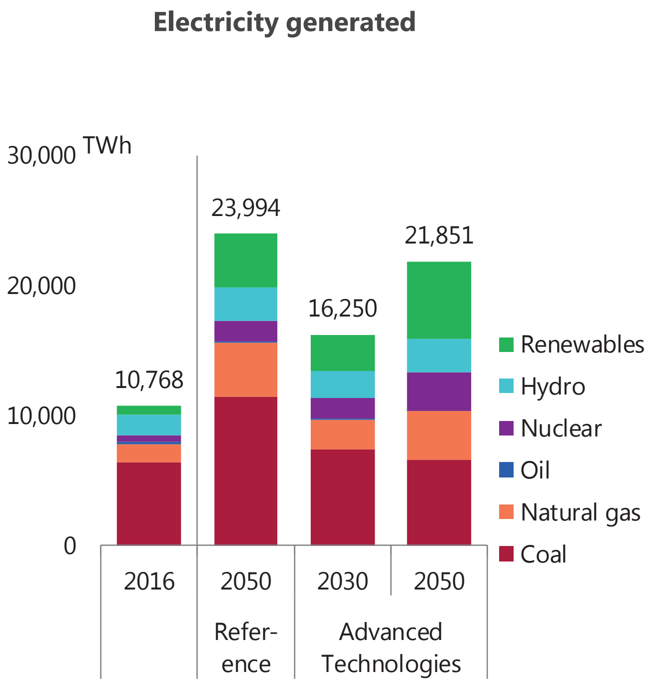


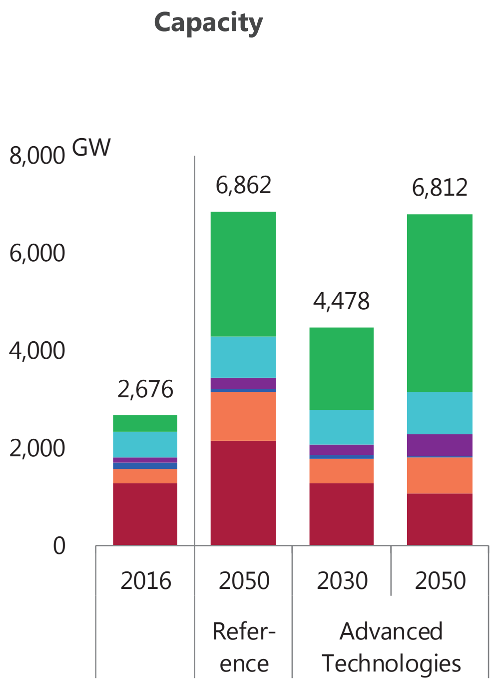
Power generation mix





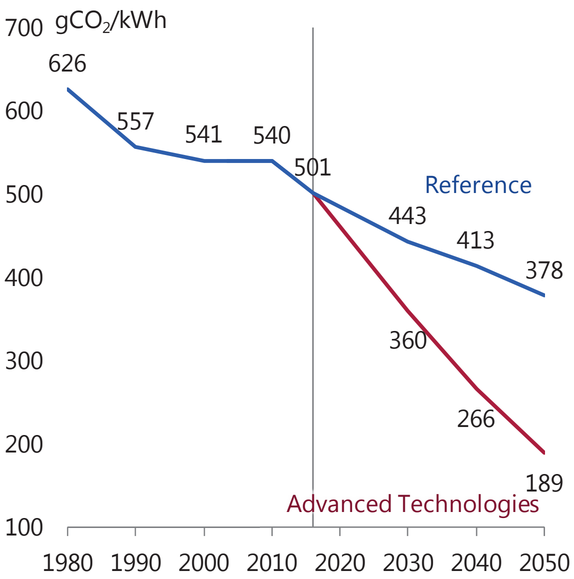
Power generation mix (Asia)



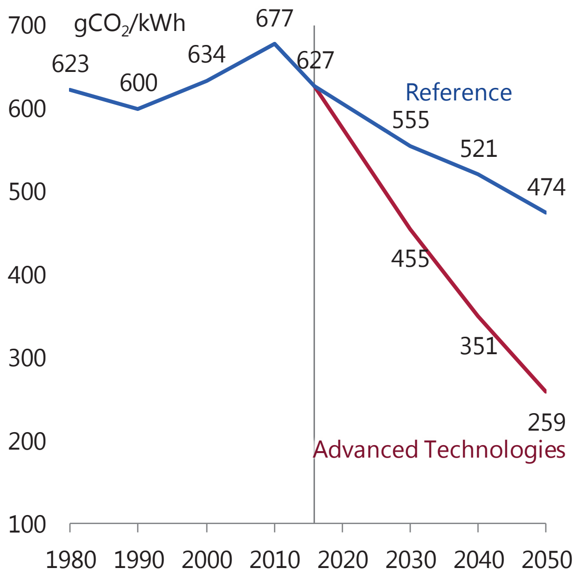


Carbon intensity of electricity

World



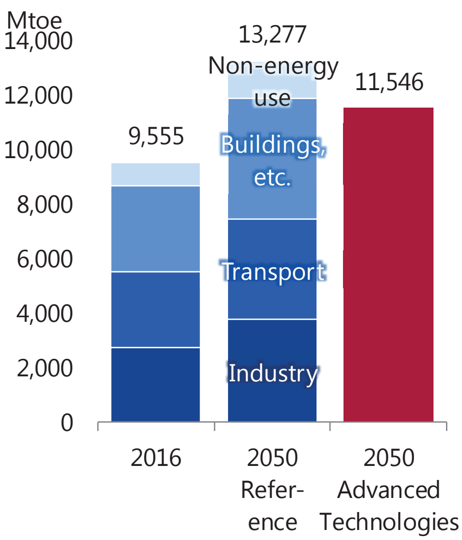
Asia



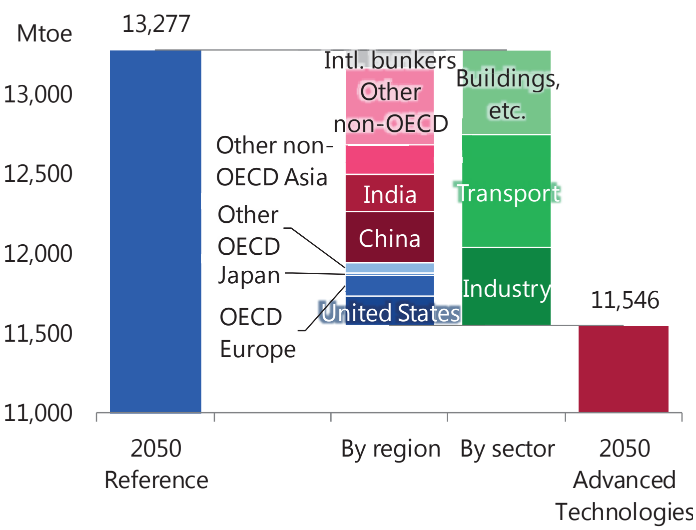
* CO_2 emissions per kWh at generation end

Energy savings (by region and by sector)

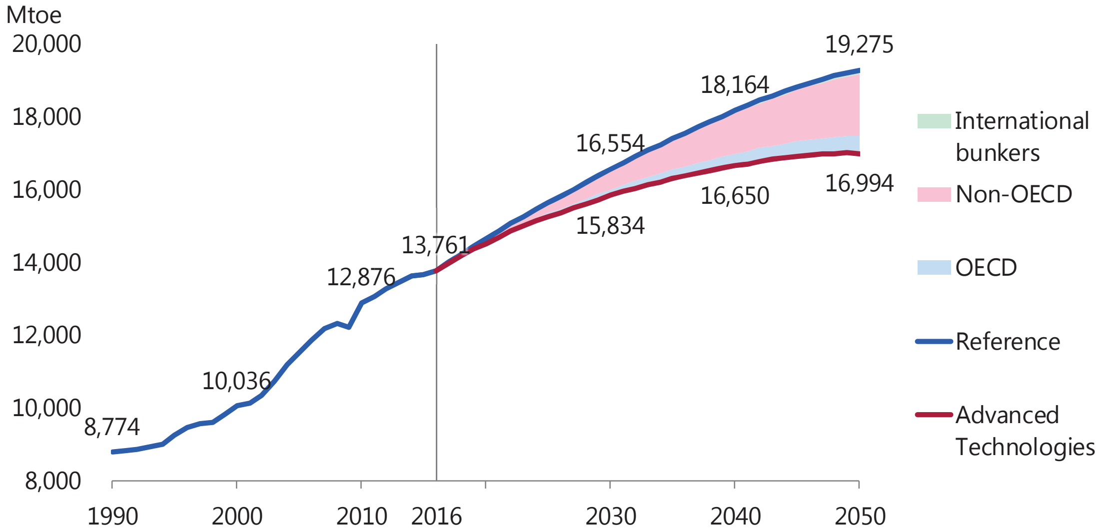
Final energy consumption



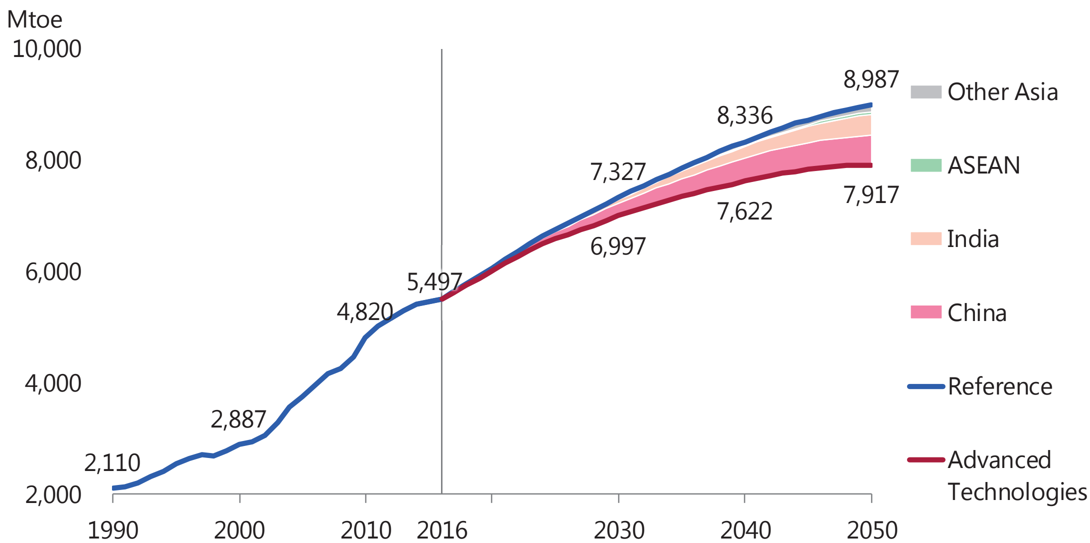
Energy savings by region and by sector



Primary energy consumption reduction

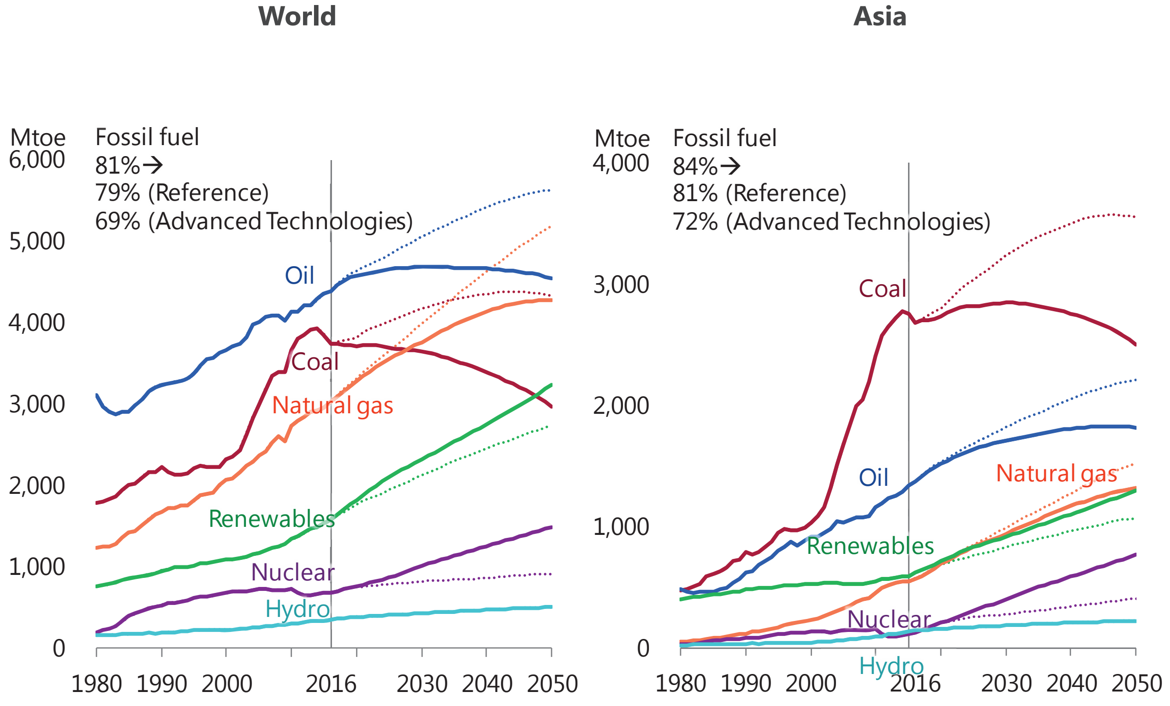


Primary energy consumption reduction (Asia)



Reference Scenario | Advanced Technologies Scenario

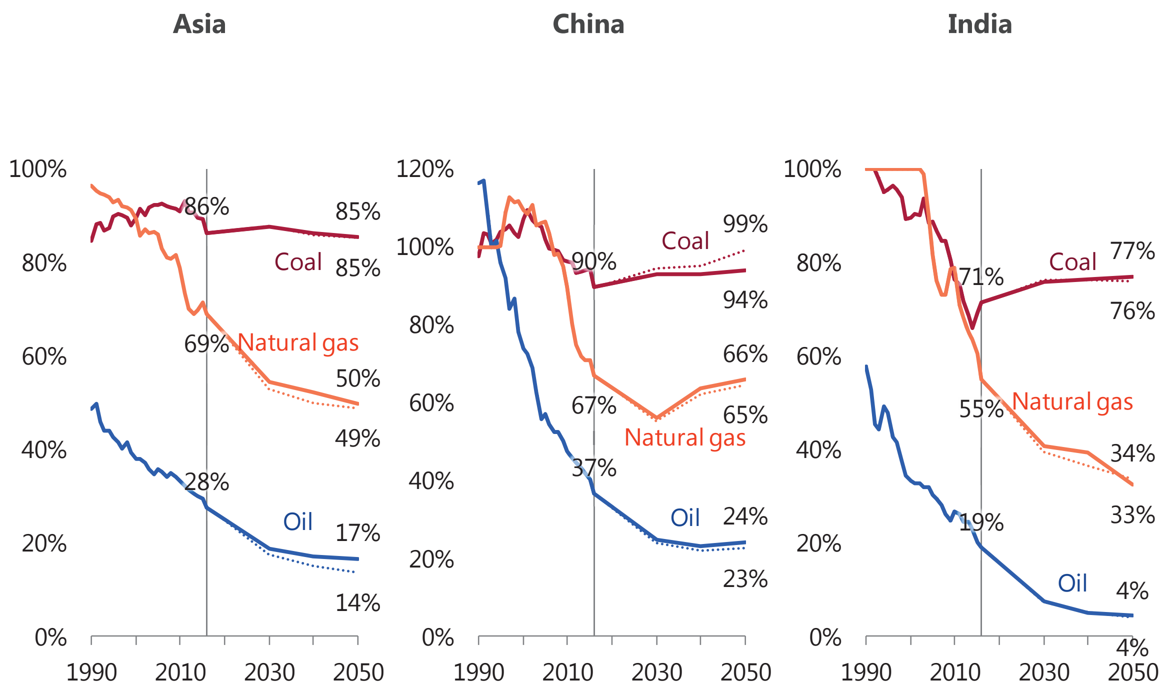
Primary energy consumption (by source)



Reference Scenario (dotted), Advanced Technologies Scenario (solid)

Reference Scenario | Advanced Technologies Scenario

Energy self-sufficiency ratio

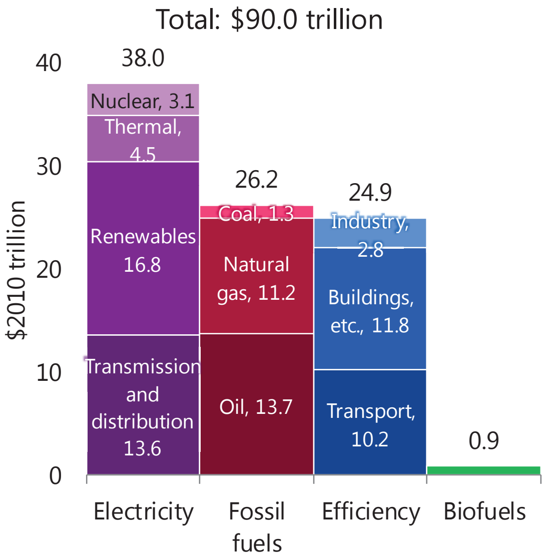


Reference Scenario (dotted), Advanced Technologies Scenario (solid)

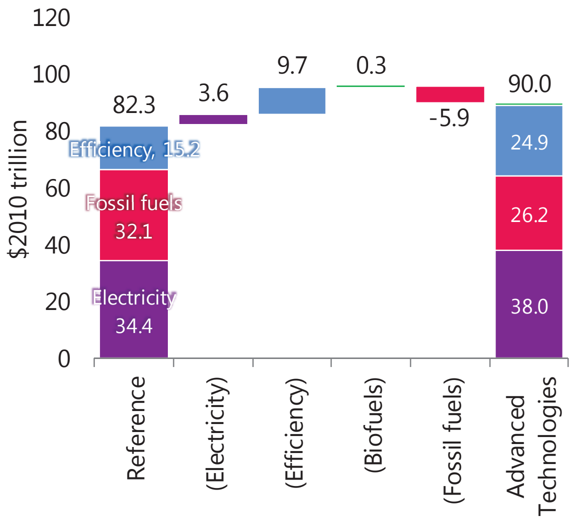
Advanced Technologies Scenario

Energy-related investments (2017 - 2050)

By sector



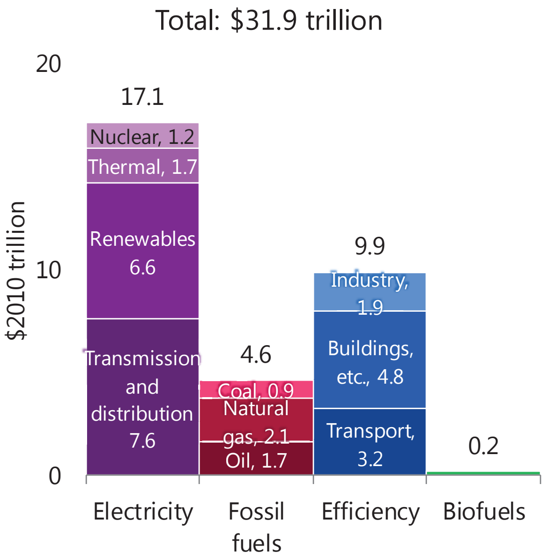
Changes from Reference Scenario



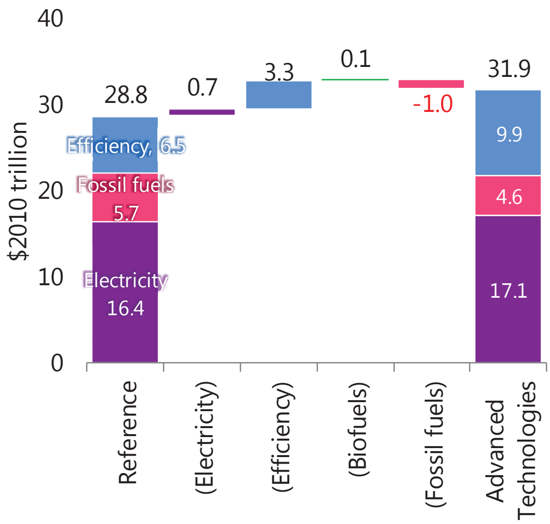
Advanced Technologies Scenario

Energy-related investments (Asia, 2017 - 2050)

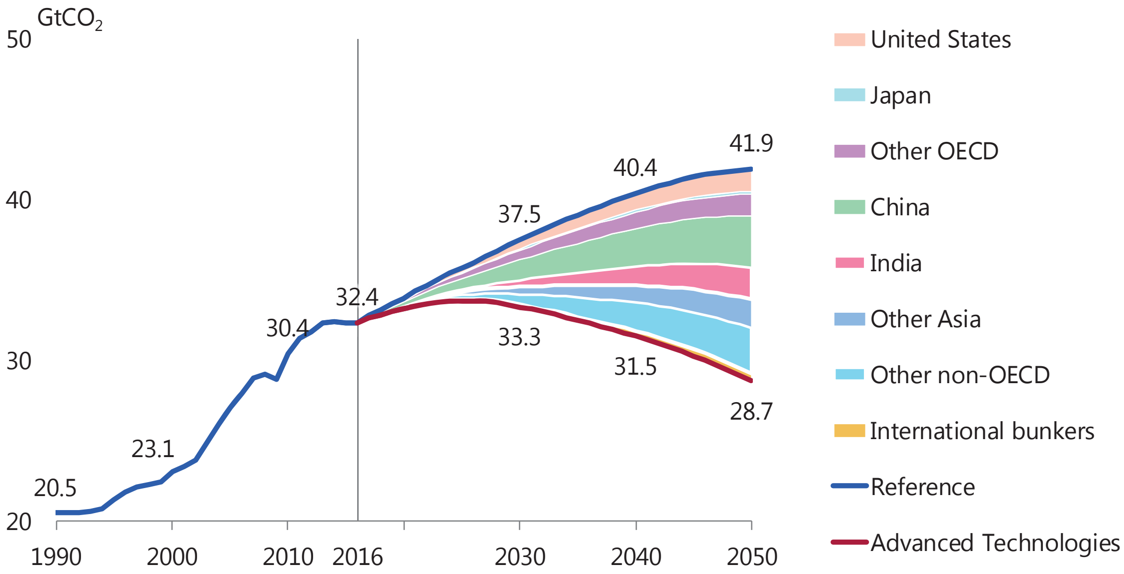
By sector



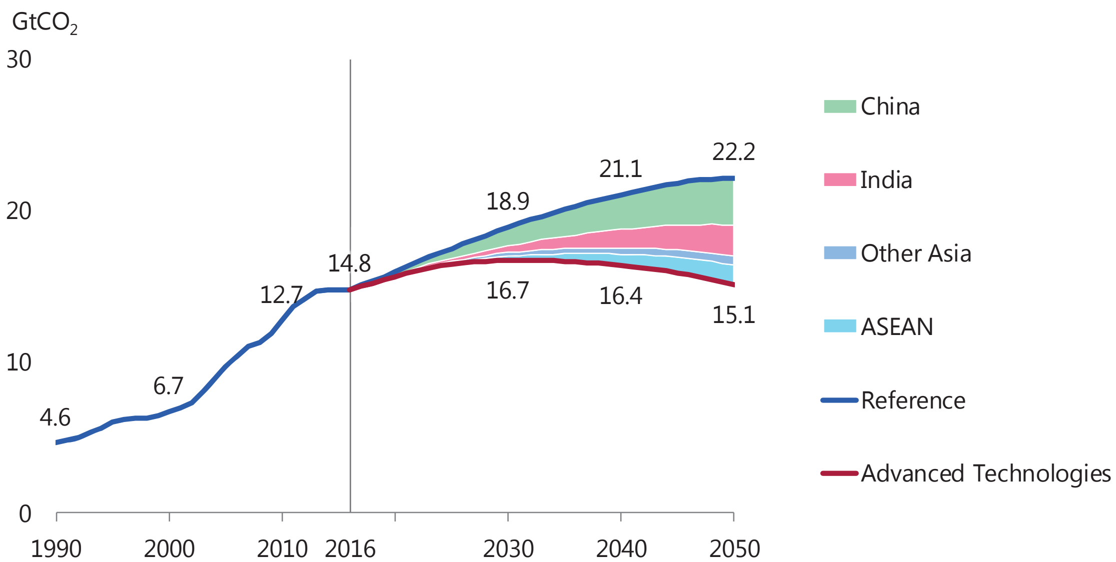
Changes from Reference Scenario



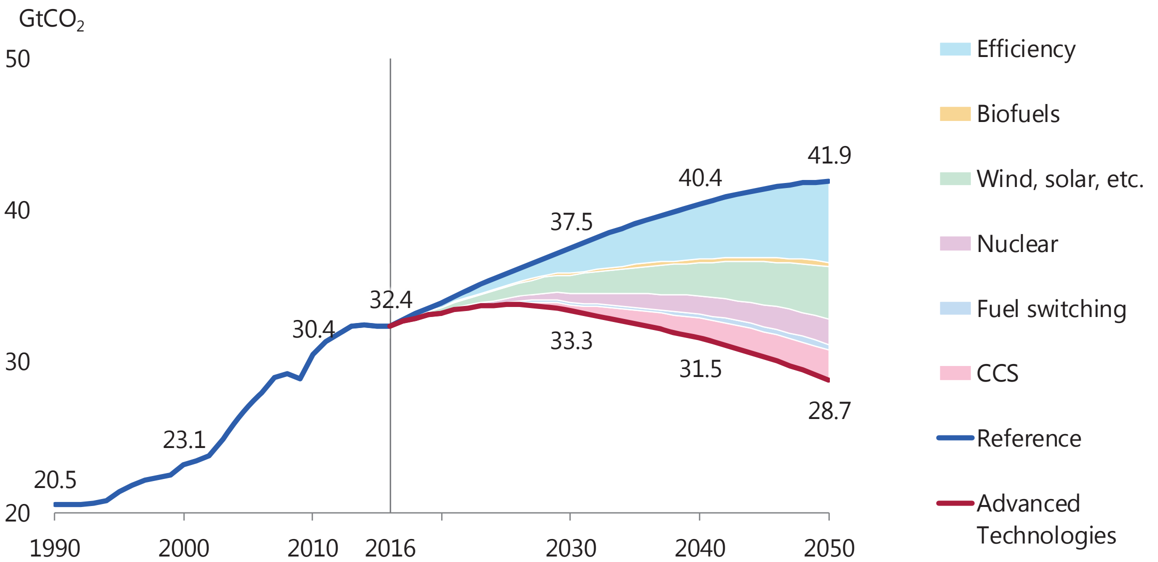
CO_2 emission reduction (by region)



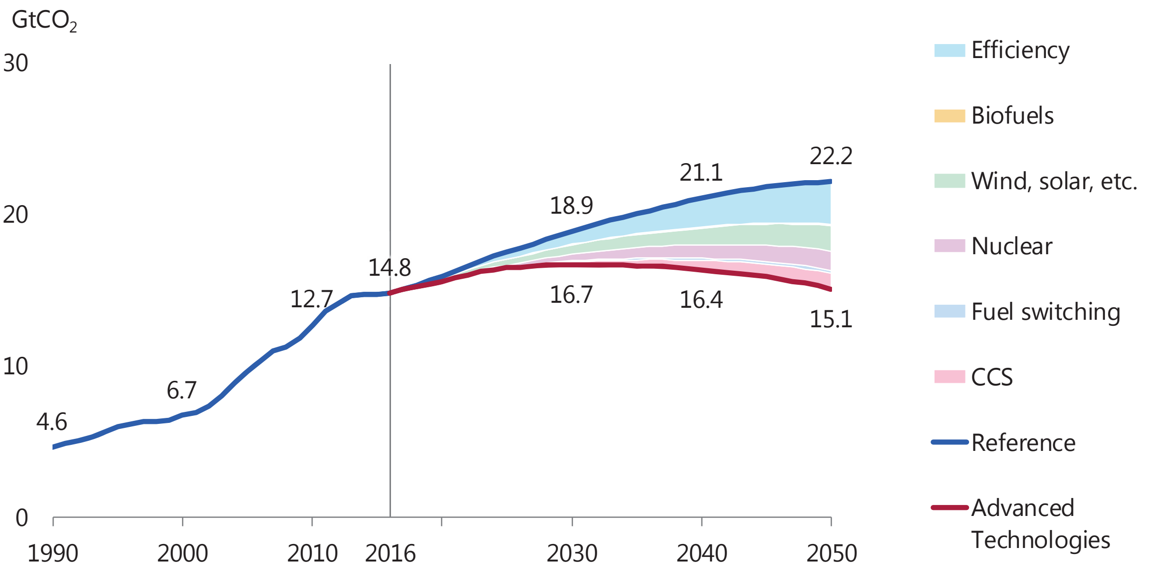
CO_2 emission reduction (Asia, by region)



CO_2 emission reduction (by technology)

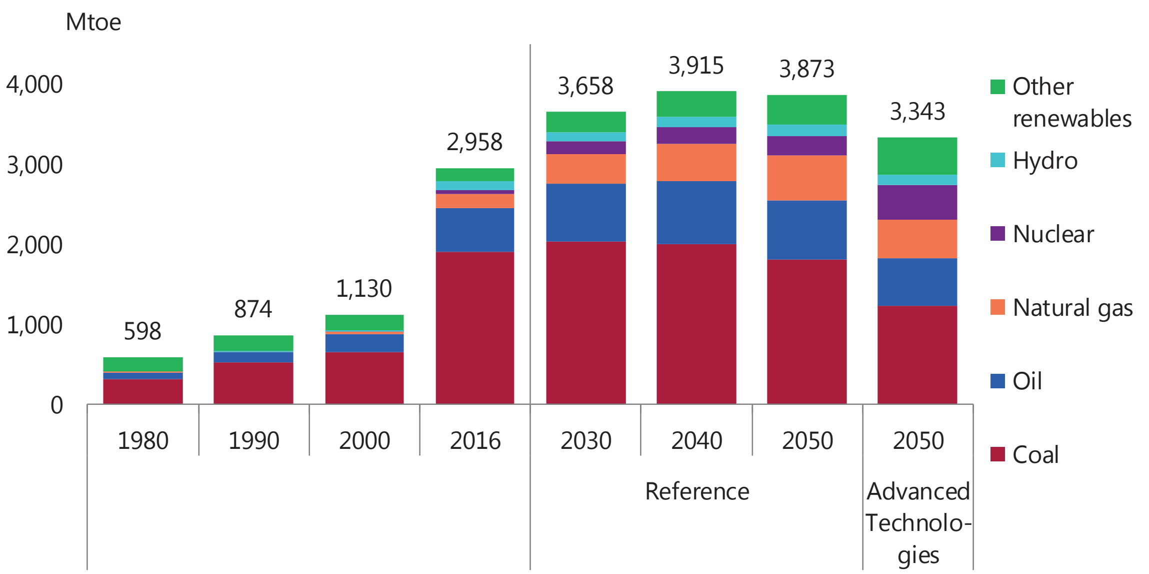


CO_2 emission reduction (Asia, by technology)

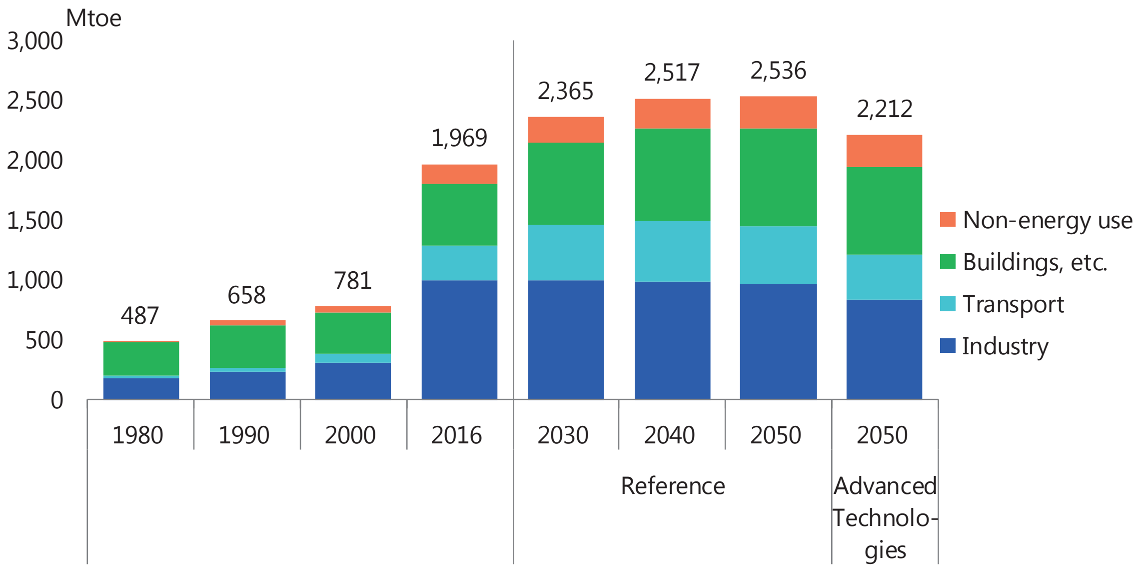


Energy outlook in China, India and ASEAN

Primary energy consumption (China)

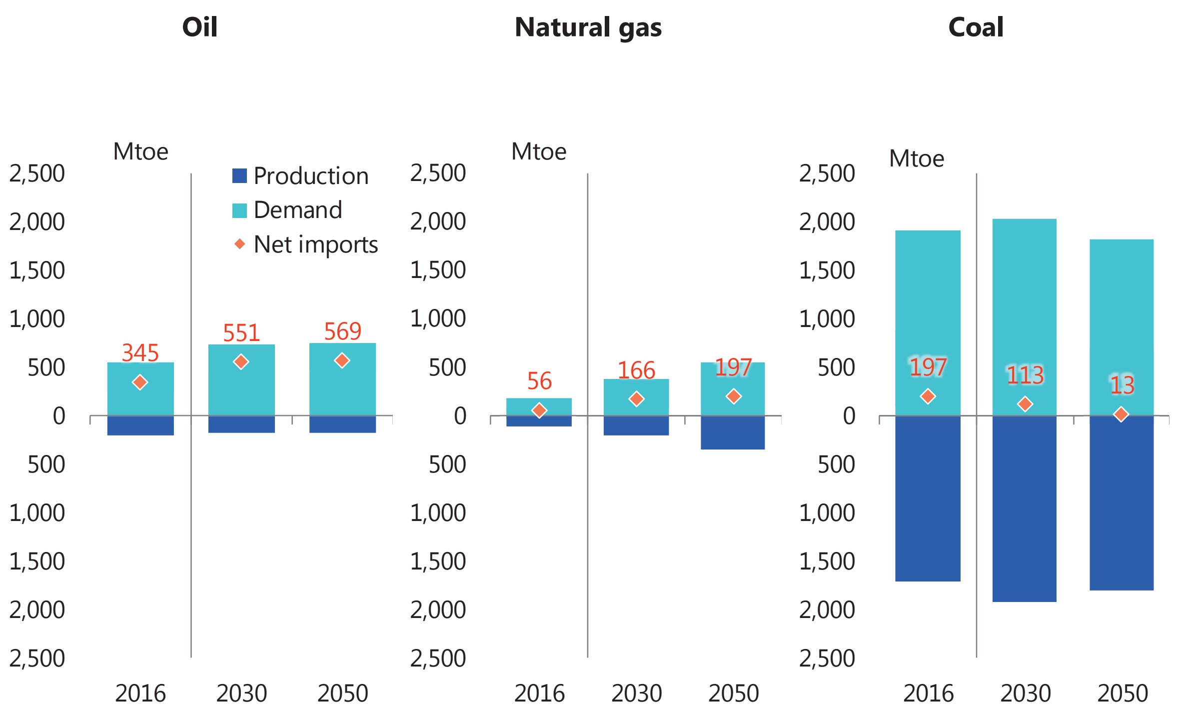


Final energy consumption (China)

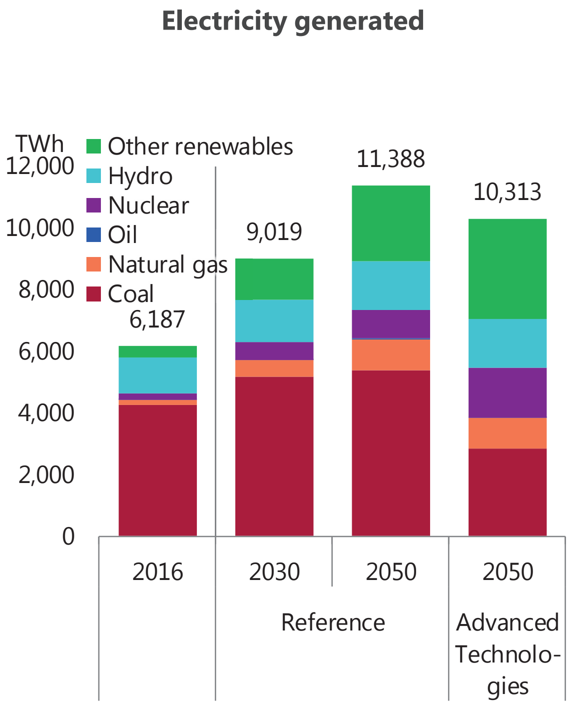


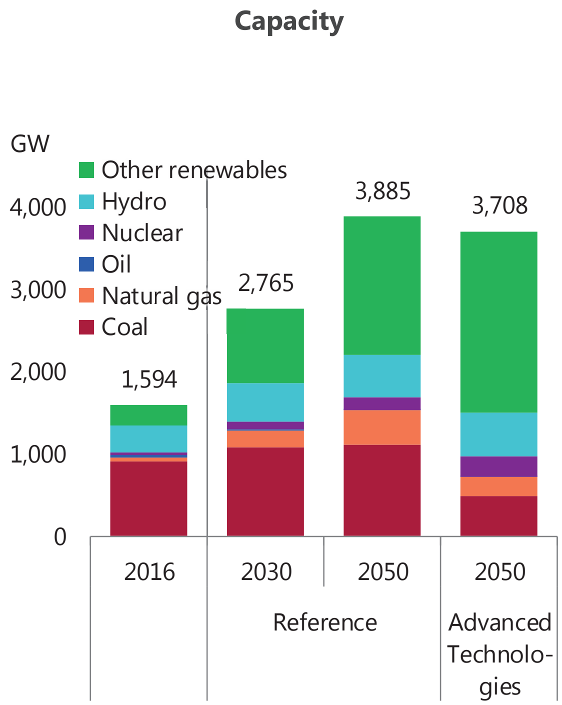
Reference Scenario

Fossil fuel supply / demand balances (China)

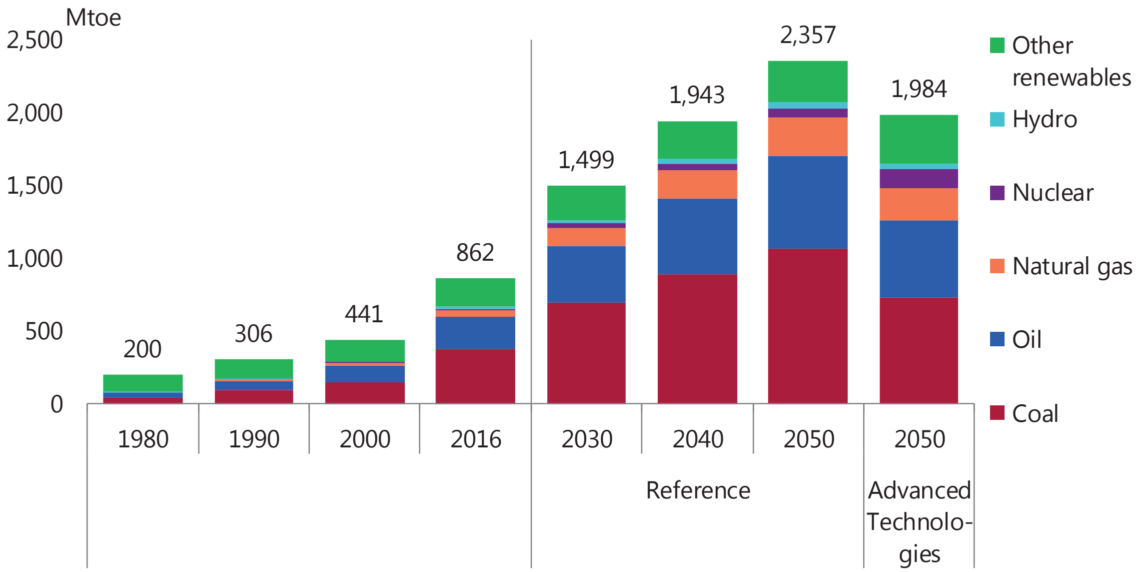


Power generation mix (China)

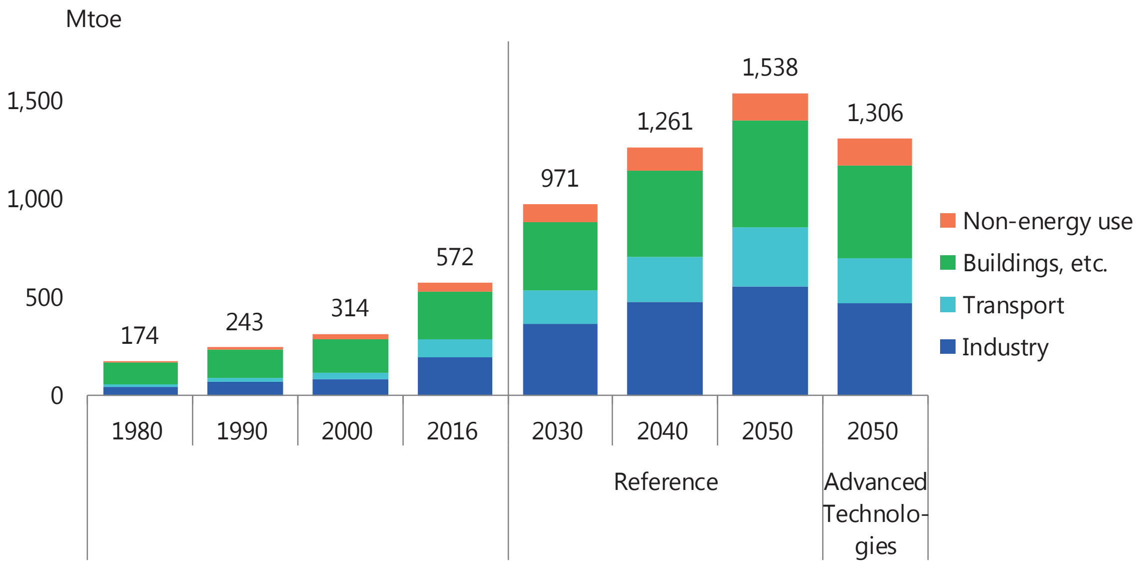




Primary energy consumption (India)

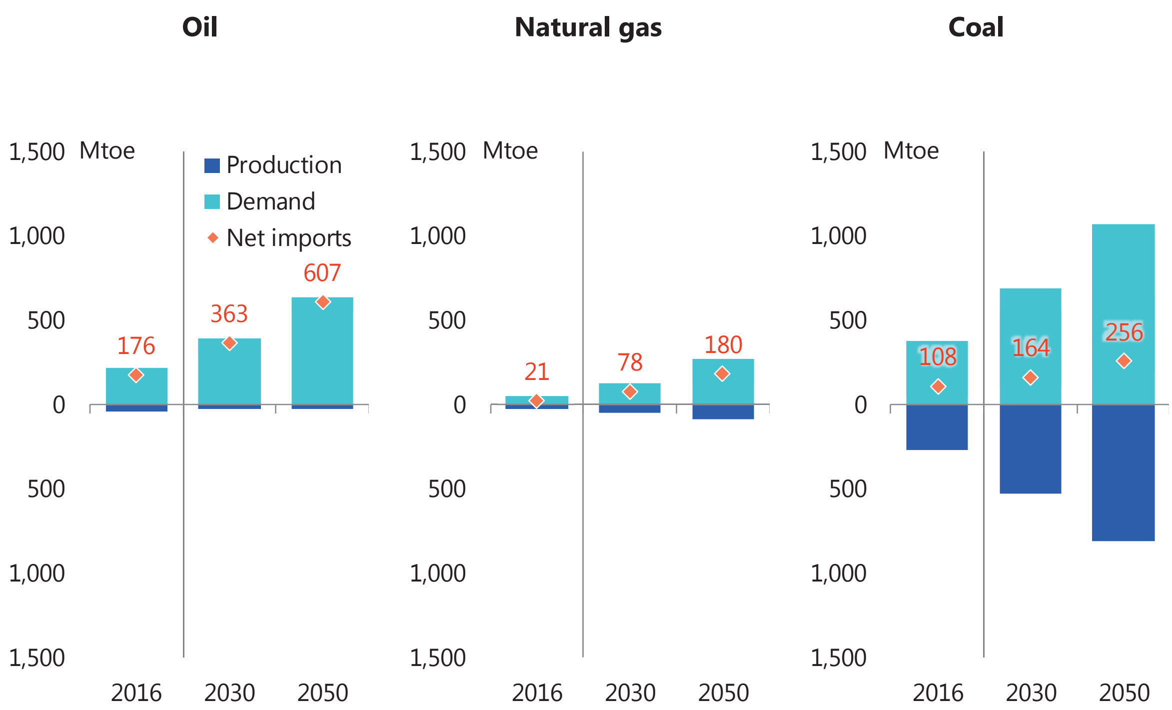


Final energy consumption (India)



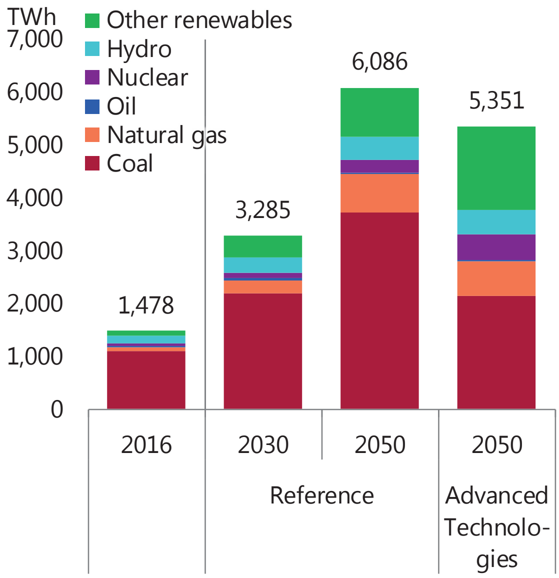
Reference Scenario

Fossil fuel supply / demand balances (India)

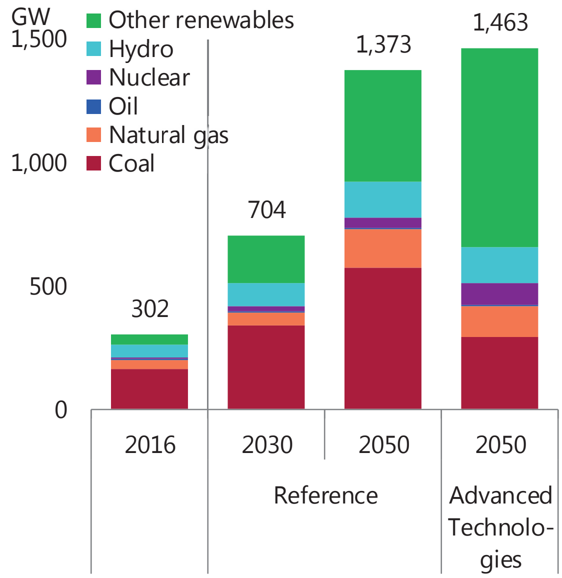


Power generation mix (India)

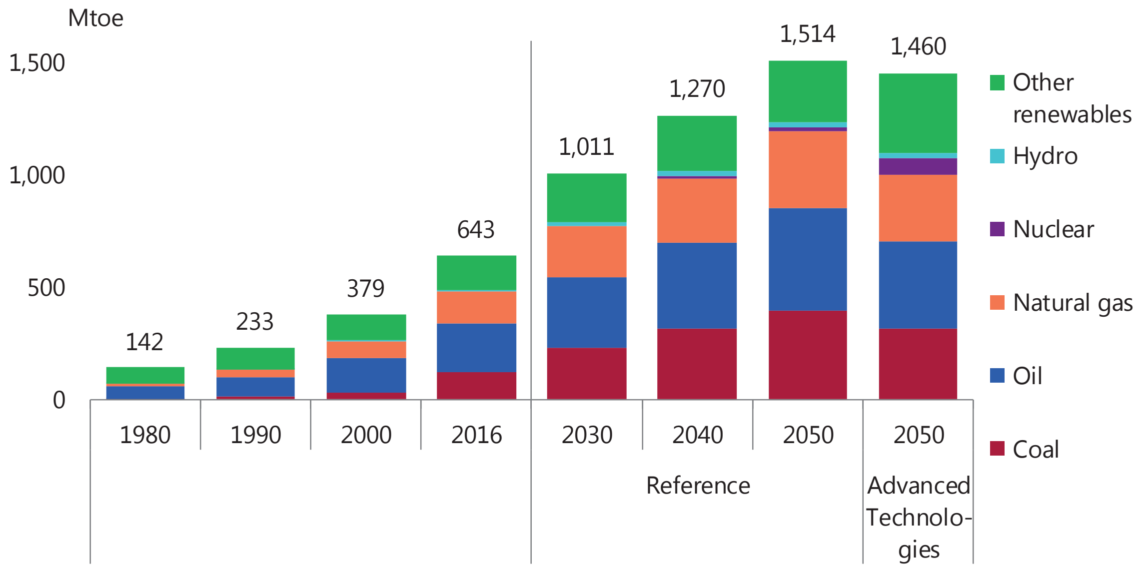
Electricity generated



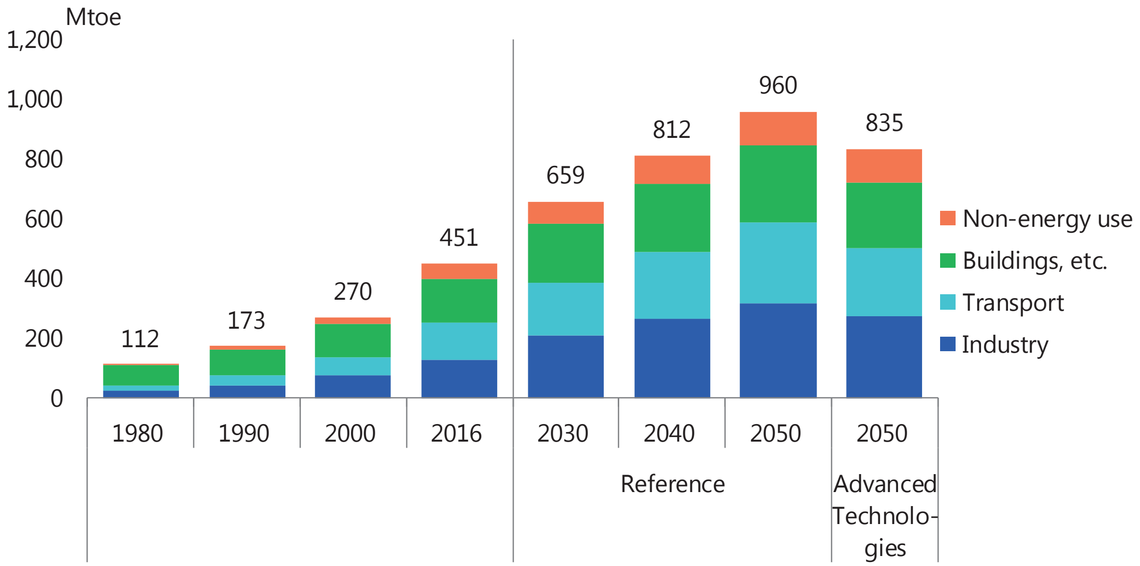
Capacity



Primary energy consumption (ASEAN)

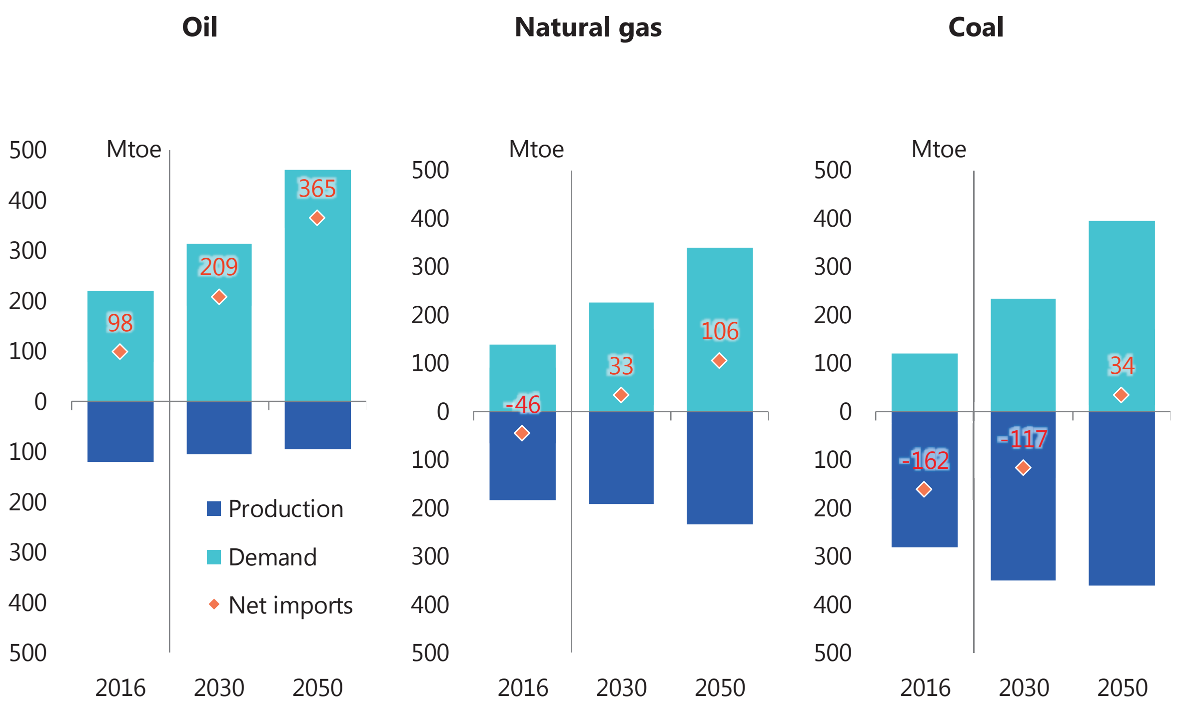


Final energy consumption (ASEAN)



Reference Scenario

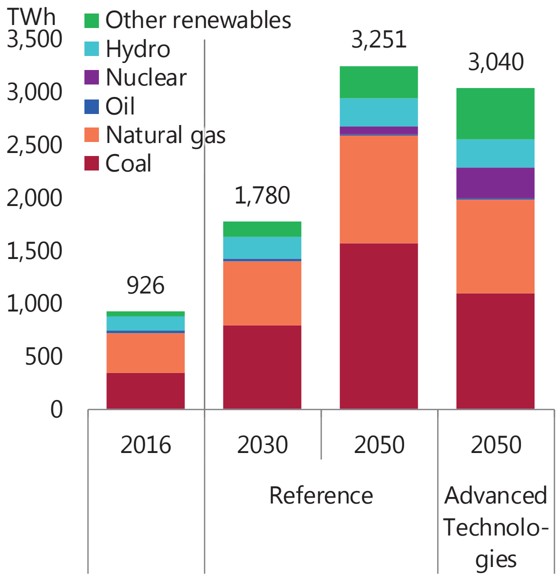
Fossil fuel supply / demand balances (ASEAN)



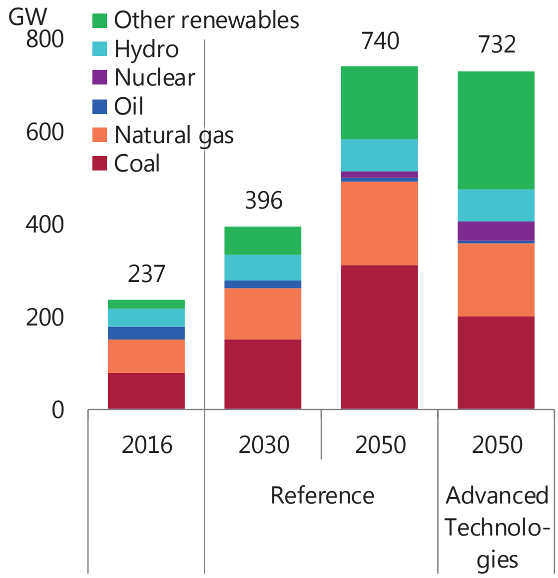
Power generation mix (ASEAN)

IEE JAPAN

Electricity generated



Capacity

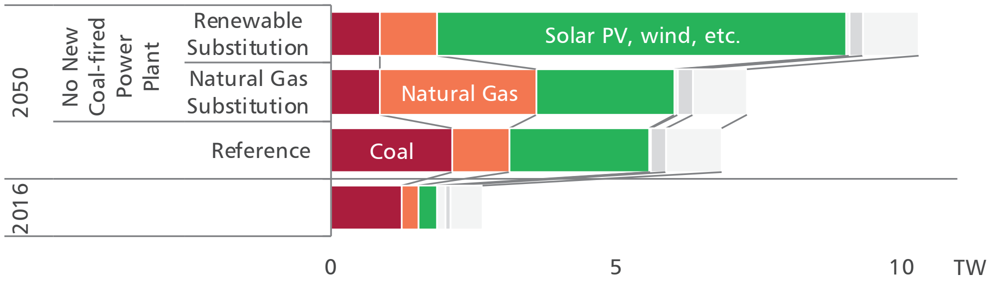


IEE JAPAN

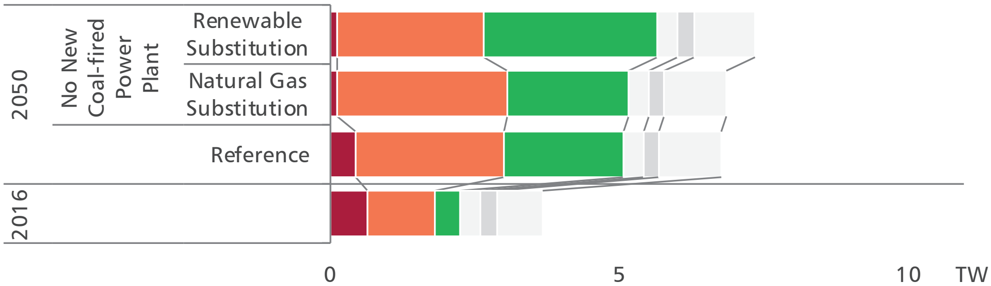
No New Coal-fired Power Plant Case

Power generation capacity «indicative»

Asia



Non-Asia



Note: No New Coal-fired Power Plant (Renewable Substitution) Case is based on approximation that curtailment of solar PV / wind power generation and battery charge are small enough to ignore. Since capacity factor of natural gas-fired power plants is same as in the Reference Scenario, the capacity is possibly overestimated.

Electricity cost estimation

Definition

Includes capital costs of power plants, fuel costs, and system costs.

It does not include financial resource of incentive for renewable energy, which has become an issue in many countries because of its amount.

2010 real price

Assumption

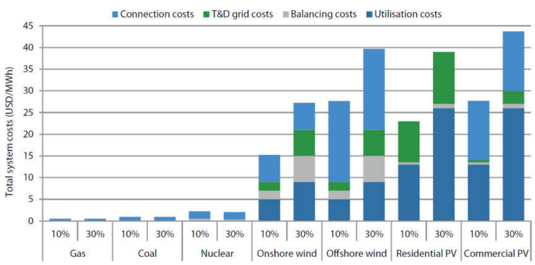
Capital costs of renewable power plants are assumed to continue to decrease until 2050. The decrease rates (solar PV: by 30%, wind: by 10% to 2050) are based on IEA "World Energy Outlook 2016."

No assumption of additional learning effect of additional capacity from the Reference Scenario

Grid and connection costs are set with reference to NEA "The Full Costs of Electricity Provision" (2018).

As for grid / connection costs, no regional specification

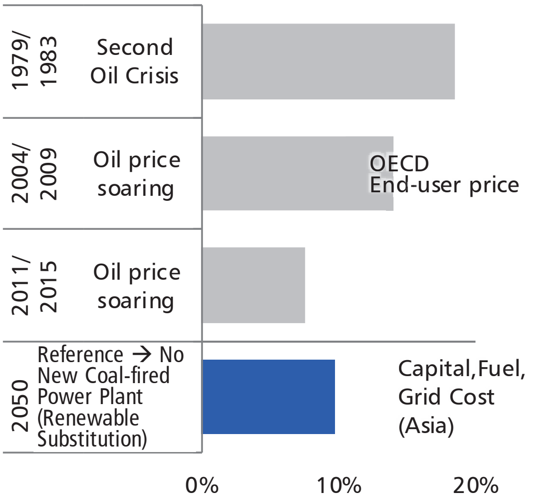
Figure 3.3: **System cost of different generation technologies**



Source: OECD/NEA "The Full Costs of Electricity Provision"

Electricity cost and price

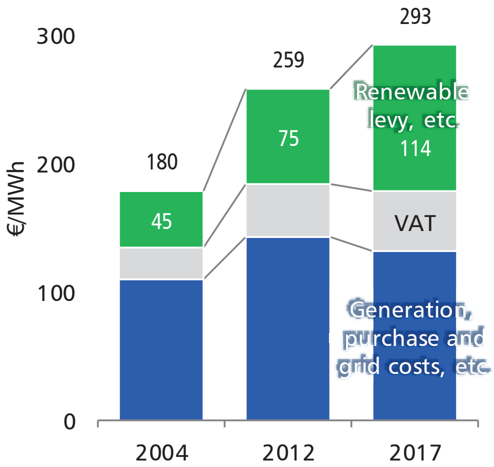
❖ Changes in real electricity cost and price



Transition from the Reference Scenario to the No New Coal-fired Power Plant (Renewables Substitution) Case raises electricity cost by 10% in Asia in 2050.

Source: IEA “Energy Prices and Taxes” [OECD end-user price]

❖ Electricity price (Germany, household)



Electricity prices do not depend on only power generation costs. In Germany, renewable levy mainly leads rise of electricity prices despite buying price reduction.

Source: BDEW “BDEW - Strompreisanalyse Mai 2018”

IEEJ Outlook 2019

October 2018

The Institute of Energy Economics, Japan

Contact :report@tky.ieej.or.jp